

APPENDIX B

RECLAMATION COVER PERFORMANCE MODELING

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RECLAMATION COVER PERFORMANCE MODELING
ZORTMAN & LANDUSKY MINES

1.01 INTRODUCTION AND TERMS OF REFERENCE

The cover modeling for preparation of the 1996 FEIS was carried out using the HELP model (Schroeder et al., 1994). Although the HELP model is widely used and accepted by the regulatory agencies for the design of covers for land fill and other waste repository sites, it is a relatively crude model which has been replaced for modeling studies such as this one, by more sophisticated programs over the last few years. The HELP model is not well suited for simulating the performance of soil cover systems, in particular in arid or semi-arid climates, where evaporation and unsaturated flow are an important aspect of cover performance (Morris and Stormont, 1997; Meyer and Gee, 1999; RGC, 2000). Therefore, the work completed for the Multiple Accounts Analysis (MAA) process utilized the SoilCover and SEEP/W software programs.

The cover modeling completed for the technical working group during the MAA process included a brief evaluation of modifications to the ROD-specified water barrier and water balance cover designs using the HELP model (Schroeder et al., 1994); a review of the HELP modeling performed for preparation of the 1996 FEIS; and the additional modeling of the specific reclamation alternative covers using the modeling programs SoilCover and SEEP/W.

Based on the testwork completed, it became clear that the MAA alternatives should include options to those cover design(s) specified in the ROD. There are various reasons why cover options were evaluated. For one, cover layer thickness and the use of GCL liners and clay layers are cost-sensitive items and needed to be re-evaluated. There are also insufficient sources of locally available, geochemically suitable borrow materials to construct the ROD-specified cover systems (e.g. top soil, coarse sand & gravel). Technical difficulties with some aspects of the cover systems specified in the ROD also play a role. For example, geosynthetic clay layers and PVC liners have a limited lifetime. The cover systems specified in the ROD are “high-cost” covers designed to minimize the net percolation (infiltration) through the waste rock material. However, although these covers may minimize infiltration for the time period until they break down (perhaps 100 years), long-term water collection and treatment will still be required. Under these conditions a lower cost cover can achieve the objectives of long-term infiltration minimization, reducing the costs of long-term treatment. The performance of alternative “lower-cost” covers was therefore evaluated.

The main components of the cover modeling undertaken included:

- use of the one-dimensional saturated-unsaturated coupled heat and mass transfer model SoilCover to predict net percolation through the cover. SoilCover is the state-of-the-art model for predicting the performance of mine waste cover systems, in particular for partially saturated covers in semi-arid climates where evaporation/transpiration is an important aspect of cover performance. The model algorithm calculates surface evaporation rates (based on daily climate data) and predicts water vapor flow and oxygen transfer in the waste and cover material profile.
- use of the two-dimensional saturated-unsaturated model SEEP/W to evaluate cover performance for sloped surfaces where lateral moisture movement is a significant component of the cover water balance.
- evaluation of alternative cover systems (e.g. “low-cost” water balance cover on flat surfaces; “capillary-break” cover on sloped surfaces) not considered in the ROD analysis; and
- evaluation of alternative cover materials (such as the Ruby Gulch tailings) not considered in the ROD analysis.

The work scope for cover modeling was aimed at evaluating alternative cover designs (not originally considered in the FEIS) that can be constructed with locally available material. The emphasis was on alternative cover systems which are technically feasible and emphasize long-term performance and sustainability.

A detailed physical laboratory testing program was carried out as part of this work scope to provide a basis for the design of alternative cover options and subsequent performance analyses using the numerical models. The laboratory testing program focused on the determination of geotechnical soil properties relevant to cover performance (grain size, Proctor test; Ksat and soil moisture retention). Both potential cover materials as well as mine rock samples were analyzed to provide realistic input parameters for cover performance modeling.

The results of the physical testing of potential cover materials and mine rock are summarized in Section 2. The cover performance modeling for alternative cover options on flat surfaces, carried out using SoilCover, is discussed in Section 3. Section 4 summarizes the results of the cover performance modeling for sloped surfaces using SEEP/W. The laboratory data, and more detailed interpretation of the results can be found in RGC Reports No. 075001/5 (RGC, July 2000) and 075001/7 (RGC, December 2000).

1.02 PHYSICAL CHARACTERIZATION

Field Sampling

A total of 18 samples of potential cover materials and mine rock material (from leach pads) were collected for laboratory testing during the 1999 field season. Table B-1 summarizes the sampling locations and type of material collected.

The emphasis of field sampling was on potential cover materials and included fine-grained material from the Goslin Flats area (4 samples), stockpiled topsoil (2 samples), Emerson shale from stockpile and pit (3 samples) and Ruby Gulch tailings (3 samples). Mine rock samples were taken from two leach pads at Landusky (LP 80/82 and LP 83) and one leach pad at Zortman (LP 84).

The majority of samples were taken from shallow test pits (3-6ft deep) using a backhoe. At those sampling locations where access was restricted (e.g. in-pit samples) samples were taken from the near-surface by hand. The finer-grained materials were collected as bulk grab samples (i.e. no screening in the field). In contrast, most coarse-grained material (including all mine rock from the leach pads) was screened in the field by passing it over a 1" sieve. Samples were placed in 2-3 sealed 20L plastic buckets and shipped to the soil laboratory of Daniel B. Stephens and Associates (DBSA) in Albuquerque, New Mexico for further testing. The percentage of oversized material was estimated (where required) at a later date by re-sampling the test pits and determining the weight of the oversized material relative to the weight of the material passing the 1" sieve.

Laboratory Methods

Table B-2 summarizes the laboratory tests performed on the various cover and mine rock samples. Grain size analyses were performed on all samples. Based on the results of the grain size analyses samples were selected for more detailed testing including initial bulk density, compaction tests (Standard proctor), permeability testing, and soil moisture retention. Details of the test methods are provided in RGC Report No. 075001/5 (RGC, July 2000).

TABLE B-1 - SUMMARY OF SOIL AND MINE ROCK SAMPLES SUBMITTED FOR PHYSICAL LAB TESTING

Sample ID	Sampling Location	Comments	Grain Size Curve		Soil Type
			% finer #4	% finer #200	
ZU/GF-300	Goslin Flats	grab sample	71%	48%	gravelly sandy silt/clay
ZU/GF-301	Goslin Flats	grab sample	90%	76%	clayey silt
ZU/GF-304	Goslin Flats	grab sample	94%	87%	clayey silt
Goslin	Goslin Flats	grab sample	99%	56%	sandy silt/clay
ZU/CCC-182	limestone outcrop	grab sample	62%	6%	sand & gravel
LDP/QR-567	Emerson Shale from East wall of Queen Rose pit	grab sample	48%	2%	poorly graded gravel w/ sand
LDWD/GBB-501	Goldbug Blue Stockpile	grab sample	68%	4%	well-graded sand w/ gravel
ZD/CCC-223	clay stockpile above Ruby Waste Dump	grab sample	95%	82%	silt/clay
Z1-1" minus	Ruby Gulch tailings (upstream)	sample screened in the field (>95% passing 1")	54%	9%	sand & gravel
Z2-1" minus	Ruby Gulch tailings (mid-stream)	sample screened in the field (>95% passing 1")	57%	5%	sand & gravel
Z3	Ruby Gulch tailings (downstream)	grab sample	61%	22%	silty sand & gravel
MG TS Top	Mill Gulch topsoil stockpile - near top of stockpile	sample screened in the field (~77% passing 1")	~55%	25%	silty sandy gravel
MG TS Bottom	Mill Gulch topsoil stockpile - near bottom of stockpile	sample screened in the field (~77% passing 1")	~50%	~24%	gravelly sandy silt/clay
Sediment	dolomite stockpile	grab sample	78%	44%	gravelly silt/clay
L(Z)80-82 LP	Landusky leach pad #80/82	sample screened in the field (~58% passing 1")	~28%	~2%	well-graded gravel with sand
L(Z)-83	Landusky - leach pad #83	sample screened in the field (~53% passing 1")	~18%	~1%	well-graded gravel with sand
Z-84	Zortman - leach pad #84	sample screened in the field (~59% passing 1")	~27%	~3%	well-graded gravel with sand
N. Alabama	material from Alabama pit (north wall)	grab sample	16%	3%	poorly graded gravel

Note:

- 1) sample ID in brackets shows label used during initial sampling and shipping
- 2) proportion of material passing 1" sieve was estimated during separate sampling event

TABLE B-2 - SUMMARY OF TESTS PERFORMED

Laboratory Sample Number	Initial Soil Properties ¹ (θ , ρ_d , ϕ)	Saturated Hydraulic Conductivity ²		Moisture Characteristics ³					Unsaturated Hydraulic Conductivity	Particle Size ⁴			Effective Porosity	Particle Density	Air Permeability	1/3, 15 Bar Points and Water Holding Capacity	Atterberg Limits	Proctor Compaction
		CH	FH	HC	PP	TH	WP	RH		DS	WS	H						
ZU/GF 300	X		X	X	X	X		X	X		X	X						X
ZU/GF 301			X								X	X						X
ZU/GF 304	X	X		X	X			X	X		X	X						X
ZU/CCC 182										X								
LDP/QR 567										X								
LDWD/GBB 501										X								
ZD/CCC 223											X	X						
ZU/GF 304(100% Proctor)			X															
LDWD\GBB 501(6")	X	X		X	X			X	X									X
N. ALAB										X								
Goslin			X								X	X						X
Z-1 1" minus	X	X		X	X	X		X	X		X	X						X
Z-2 1" minus		X									X	X						X
Z-3											X	X						X
Z-3-A	X	X		X	X	X		X	X									
Z-84	X	X		X	X			X	X		X	X						
L83		X								X								
MG TS Top	X	X		X	X	X		X	X		X	X						X
MG TS Bottom		X									X	X						X
L82/83		X								X								
Sediment											X	X						

¹ θ = Initial moisture content, ρ_d = Dry bulk density, ϕ = Calculated porosity

² CH = Constant head, FH = falling head

³ HC = Hanging column, PP = Pressure plate, TH = Thermocouple psychrometer, RH = Relative humidity box

⁴ DS = Dry sieve, WS = Wet sieve, H = Hydrometer

Results and Discussion

A summary of the physical soil properties are provided in this section and the reader is referred to RGC Report No. 075001/5 for details (RGC, July 2000).

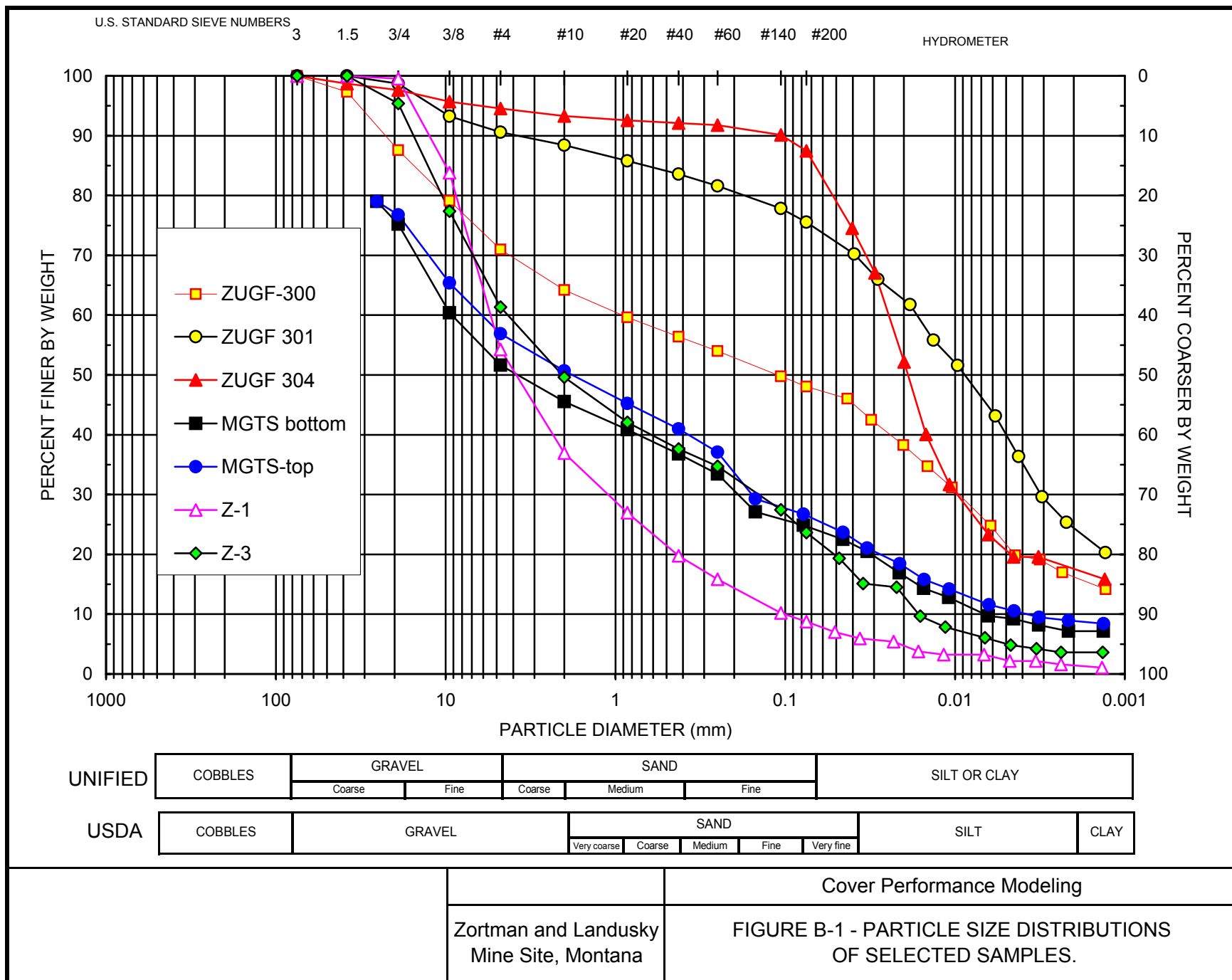
Figure B-1 shows the particle size distribution (PSD) of selected samples representing potential cover materials. The various materials showed significant variations in the fines content ranging from ~10-80%. Figure B-2 shows the PSD for the mine rock samples collected from the three leach pads at the mines. The PSD of mine rock samples from three other mine sites are shown for comparison. The mine rock samples are very coarse and consist of poorly-graded coarse gravel with some sand. The very coarse nature of the mine rock samples suggests that they have a very low moisture retention capacity and may act as a capillary barrier when covered with finer-grained soils.

The detailed results of the moisture contents, densities and porosities of selected samples are provided in Table B-3. The in-situ moisture content correlated very well with the fines content of the sample. The initial (or in-situ) moisture contents (by volume) ranged from 26.6% for the fine-grained Goslin Flats material to as low as 3% for the coarse tailings. The topsoil and the mine rock sample Z-84 showed intermediate moisture contents (13% to 16% by volume).

Table B-4 summarizes the results of the Proctor compaction tests for the finer-grained materials (Proctor testing on the coarse mine rock samples was not feasible) and Table B-5 summarizes the results of the saturated hydraulic conductivity tests.

The Goslin Flats material showed the lowest saturated hydraulic conductivity of all tested samples with K_{sat} values ranging from 8×10^{-7} to 5×10^{-6} cm/s (Table B-5). Upon compaction, the hydraulic conductivity was reduced by about one order-of-magnitude (2×10^{-7} cm/s). The saturated hydraulic conductivity for the topsoil samples was about 2 orders-of-magnitude higher than that of the Goslin Flats material (3×10^{-4} to 6×10^{-4} cm/s) (Table B-5). The Ruby Gulch tailings showed a significant variation in saturated hydraulic conductivity ranging from as high as 2×10^{-2} cm/s for the coarse tailings to as low as 3×10^{-4} cm/s for the fine-grained tailings. The hydraulic conductivity of the mine rock samples varied from 1×10^{-3} cm/s to 6×10^{-3} cm/s.

Figure B-3 shows the soil water characteristic curves (SWCC) determined in the laboratory on various potential cover materials and on one mine rock sample (Z-84). The SWCCs of mine rock samples from other sites (with similar coarse PSD as the mine rock at Zortman-Landusky) are also shown for comparison. The SWCC represents the volumetric moisture content of the material as a function of the suction (negative pressure) in the unsaturated sample. An important point on the SWCC is the air entry value (AEV), which is defined as the suction value at which the volumetric water content declines, i.e. where the soil begins to drain (AEV). The AEV is critical for cover performance as it represents the suction at which the first (largest) pores drain (i.e. the soil changes from tension-saturated to unsaturated conditions) with an associated large decline in the hydraulic conductivity of the soil.



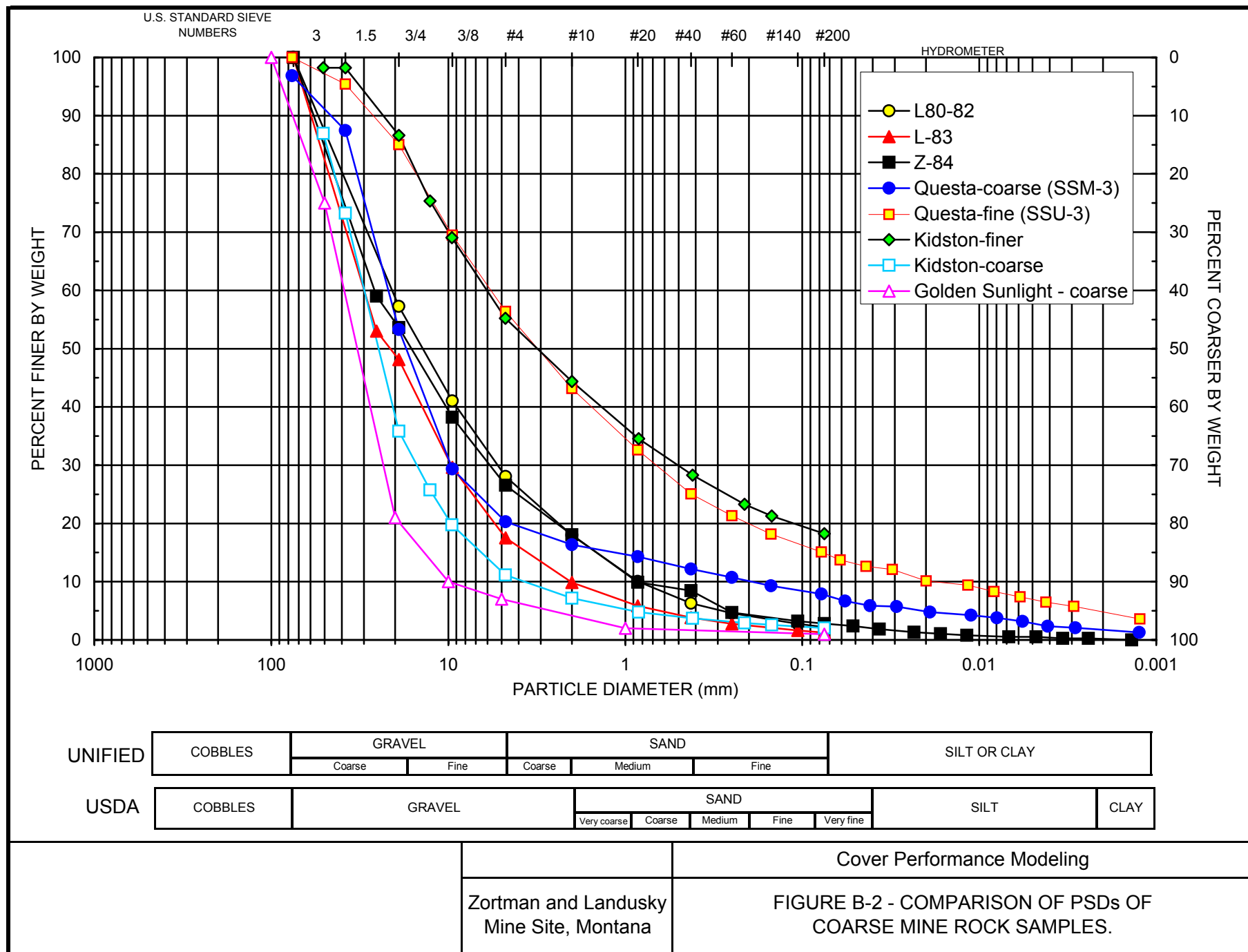


Table B-3 - Summary of Moisture Content, Densities and Calculated Porosity.

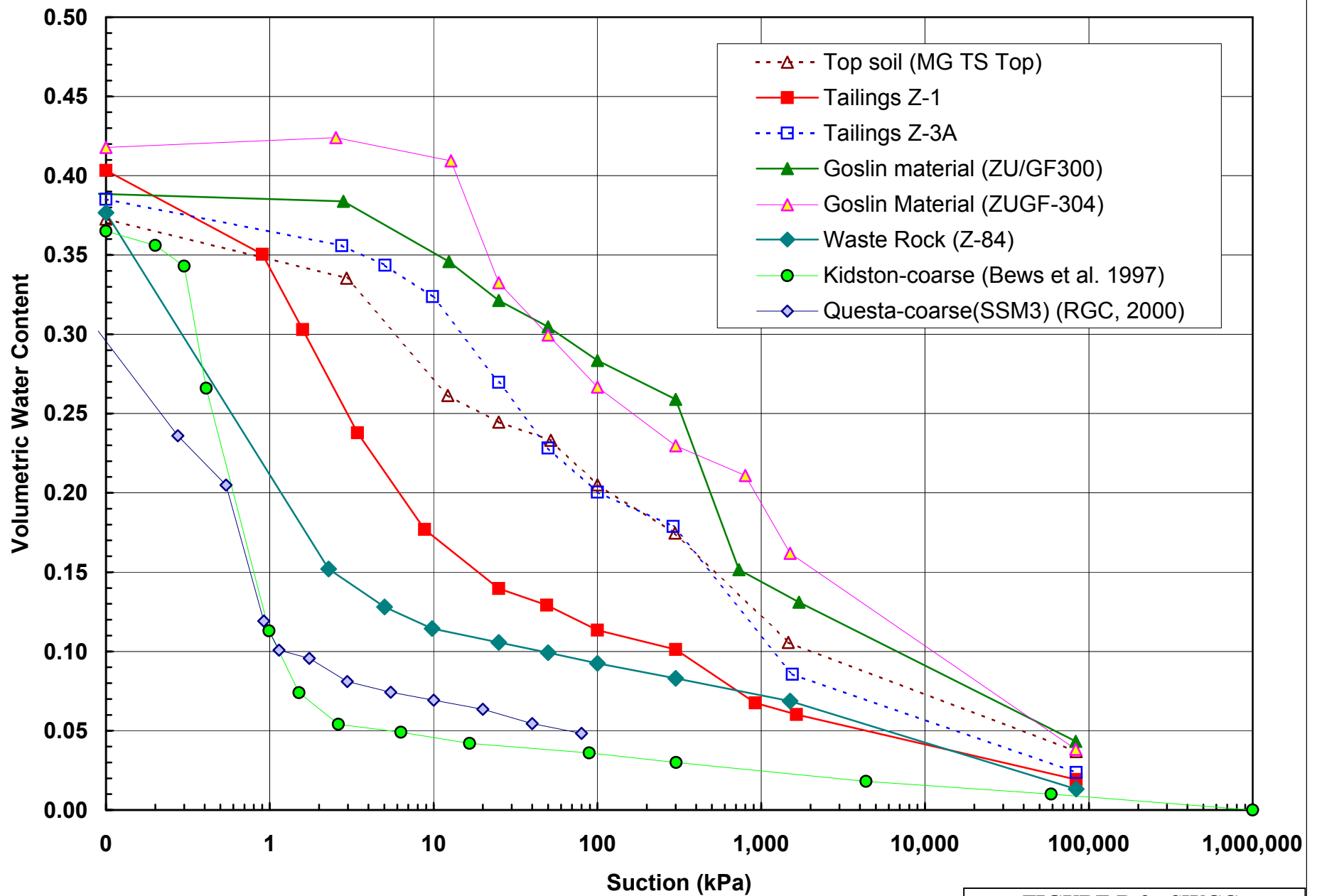
Sample Number	Initial Moisture Content		Dry Bulk Density (g/cm ³)	Wet Bulk Density (g/cm ³)	Calculated Porosity (%)
	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)			
ZU/GF 300	13.9	23.6	1.69	1.93	36.1
ZU/GF 304	16.8	26.6	1.58	1.85	40.2
LDWD\GBB 501(6")	1.8	3.1	1.76	1.79	33.6
Z-1 1" minus	3.4	5.8	1.69	1.74	36.3
Z-3-A	1.9	3.2	1.62	1.66	38.7
Z-84	8.0	13.4	1.67	1.81	36.8
MG TS Top	9.4	16.2	1.73	1.89	34.7

Table B-4 - Summary of Proctor Compaction Tests

Sample Number	Optimum Moisture Content (% g/g)	Maximum Dry Bulk Density (g/cm ³)
ZU/GF 300	12.2	1.91
ZU/GF 301	20.3	1.64
ZU/GF 304	17.1	1.74
LDWD\GBB 501(6")	8.7	1.97
Goslin	13.7	1.77
Z-1 1" minus	12.6	1.88
Z-2 1" minus	10.7	1.85
Z-3	13.3	1.82
MG TS Top	11.7	1.92
MG TS Bottom	9.5	1.93

Table B-5 - Summary of Saturated Hydraulic Conductivity Tests.

Sample Number	K _{sat} (cm/sec)	Method of Analysis	
		Constant Head	Falling Head
ZU/GF 300	5.0E-06		X
ZU/GF 301	7.6E-07		X
ZU/GF 304	4.8E-06	X	
LDWD/GBB 501	2.2E-03	X	
ZU/GF 304(100% Proctor)	2.2E-07		X
Goslin	4.7E-07		X
Z-1 1" minus	2.0E-02	X	
Z-2 1" minus	1.6E-02	X	
Z-3	2.9E-04	X	
Z-84	1.1E-03	X	
L83	5.8E-03	X	
MG TS Top	5.6E-04	X	
MG TS Bottom	3.3E-04	X	
L82/83	3.0E-03	X	



**FIGURE B-3 - SWCCs
DETERMINED ON
LABORATORY SAMPLES**

The Goslin Flats material has the highest soil moisture retention capacity of all potential cover materials with an air entry value (AEV) of about 5 to 15 kPa (50-150cm) suction. The soil (MGTS-Top) and the fine tailings (Z-3) show a fairly similar SWCC with an AEV of 2 to 5 kPa (20-50cm) suction. The fine tailings have a slightly better water holding capacity than the topsoil in the low suction range. The SWCC of the coarse tailings (Z-1) differs significantly from that of the fine tailings (Z-3) and the soil (MGTS-Top). The AEV of the coarse tailings is <1 kPa (10cm) suction and the slope of the SWCC is much steeper than that of the finer-grained materials (Figure B-3). In other words the coarse tailings are much more likely to drain under typical field conditions (suctions in the range of <1 to 100 kPa) than the fine tailings. At the same time, the ability of the soil to drain also provides more storage capacity between successive dry and wet periods.

As expected the mine rock sample (Z-84) had the lowest AEV and the steepest SWCC (Figure B-3). In fact, the water retention capacity of this sample was so low that difficulties were encountered to determine the AEV and the low suction portion of the SWCC in the laboratory. A first measurement of moisture content could only be obtained at a suction of 2.5 kPa (25 cm), at which point most of the pore water had already drained and the moisture content was close to field capacity (Figure B-3). Note that only the -#4 portion of this leach pad material could be tested due to size constraints with the laboratory apparatus (a 6" mold was used). It is likely that the bulk material present in the field (which is much coarser than the test specimen) would drain even faster, i.e. show an even steeper SWCC than was measured in the laboratory.

For comparison purposes, the SWCCs of coarse mine rock samples collected at the Questa Mine site (RGC, 2000) and the Kidston Mine site (Bews et al, 1997) are also shown in Figure B-3. Both of these mine rock samples are comparable to the Zortman-Landusky samples in that they represent poorly graded, coarse gravels. However, the sand and fines content of these mine rock samples differs somewhat and approximately brackets the range observed at the Zortman-Landusky site (see Figure B-2). The SWCCs for the Questa and Kidston samples show a similar steep decline in moisture content at very low suctions (0.1 to 1 kPa) with either no discernible AEV (Questa) or a very low AEV (Kidston) in the order of 0.3 kPa (3 cm) (Figure B-3). The field capacities of these coarse mine rock samples were less than 5% (at a suction of ~300 kPa).

The similarity in PSD of the Kidston sample to the coarse mine rock from Zortman-Landusky (in particular L-83, see Figure B-2) justified the use of the SWCC of the Kidston Mine rock sample in this cover modeling study (representing "coarse" mine rock). The SWCC of the Z-84 sample was used in sensitivity analyses to assess the influence of the SWCC of the mine rock on cover performance (see Section 3 below).

Figure B-4 provides the hydraulic conductivity functions (calculated from the SWCCs) and illustrates that the coarse tailings show the highest hydraulic conductivity of all cover materials at very low suction (close to saturation) but show the lowest hydraulic conductivity at high suctions. The opposite trend is observed for the fine-grained Goslin Flats material (ZUGF-300). Note that the large differences in hydraulic conductivity among the various potential cover materials (a range of almost four orders of magnitude) is

greatly reduced at suctions typically observed in the field (1-100 kPa). Also note that the hydraulic conductivity of all coarse mine rock samples is consistently much lower than any of the cover materials except for saturated or near-saturated conditions (<10 kPa).

1.03 COVER PERFORMANCE ON FLAT SURFACES

Modeling Approach

The modeling software SoilCover (Geo-Analysis 2000 Ltd, 2000) was used to assess alternative cover scenarios for flat (or nearly flat) surfaces. This model is a coupled heat and mass transfer, saturated-unsaturated model, which combines soil conditions with atmospheric conditions. SoilCover is capable of predicting actual evapotranspiration from the soil profile. The model input parameters include daily climate parameters (air temperature, relative humidity, pan evaporation, and precipitation) as well as soil parameters (SWCC, Ksat, hydraulic conductivity function).

The main purpose of the cover performance modeling is to predict the flux of pore water from the cover into the underlying mine rock which ultimately emerges at the base of the mine rock pile as seepage. Due to the semi-arid climate conditions at the Zortman-Landusky sites the flux of soil moisture at the cover-mine rock interface is not always downward but may also be upward (in particular during hot and dry conditions). SoilCover allows the computation of the resulting net flux of pore water (expressed as mm or inches per year) across the interface of cover and mine rock for a given time period (typically based on one calendar year or hydrologic year). This net flux is commonly referred to as the “net percolation” of the cover system.

SoilCover is a one-dimensional mode and it is implicitly assumed that the soil profile is horizontal and all soil moisture movement is vertical. Therefore, the SoilCover modeling results apply only to flat or nearly-flat surfaces. At the same time, it was assumed that the cover surface has a small slope sufficient to allow surface runoff of any excess precipitation that could not infiltrate. Surface runoff occurs when the entire cover profile is saturated and the rainfall intensity exceeds the saturated permeability of the uppermost cover layer. The modeling results indicate that this condition occurs only on a few isolated occasions during any given year. However, due to the intensity of the storm events (up to 50 mm per day) surface runoff can be significant and should be promoted by surface reshaping.

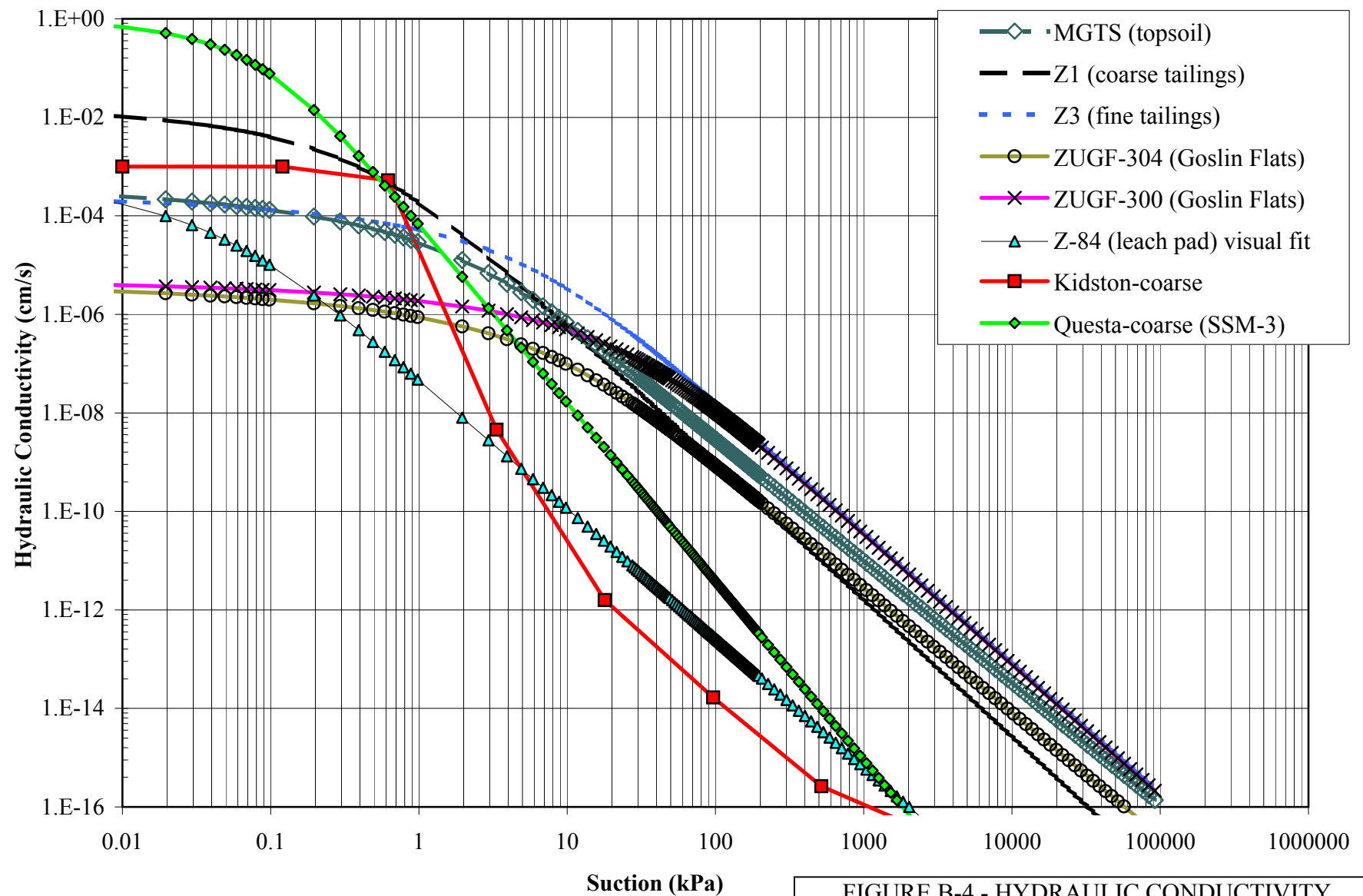


FIGURE B-4 - HYDRAULIC CONDUCTIVITY
FUNCTIONS FOR LABORATORY SAMPLES
DETERMINED USING VAN GENUCHTEN MODEL

Cover Alternatives

A total of seventeen different cover scenarios were evaluated and are summarized in Table B-6. The cover types vary in design and therefore effectiveness and cost. In the end, not all cover types were utilized in specific reclamation alternatives and certain covers were included in all the alternatives. Chapter 2 details the covers included in each of the reclamation alternatives.

Soil Properties

SoilCover requires the input of the SWCC and the saturated hydraulic conductivity (Ksat) for all materials in the modeled cover profile. SoilCover determines the relative hydraulic conductivity function by fitting the Fredlund and Xing (1994) model to the SWCC (Geoslope, 2000). The hydraulic conductivity at any given suction is then calculated as the product of the relative hydraulic conductivity value at that suction and the Ksat value input to the model.

Figures B-5 and B-6 show the SWCCs and the hydraulic conductivity functions for the potential cover materials and the mine rock used as input to the SoilCover model. Where available, the SWCC and saturated hydraulic conductivity values were taken directly from the laboratory test results, in some instances, professional judgement was used to estimate particular properties (for example with the mixed topsoil/tailings cover scenario).

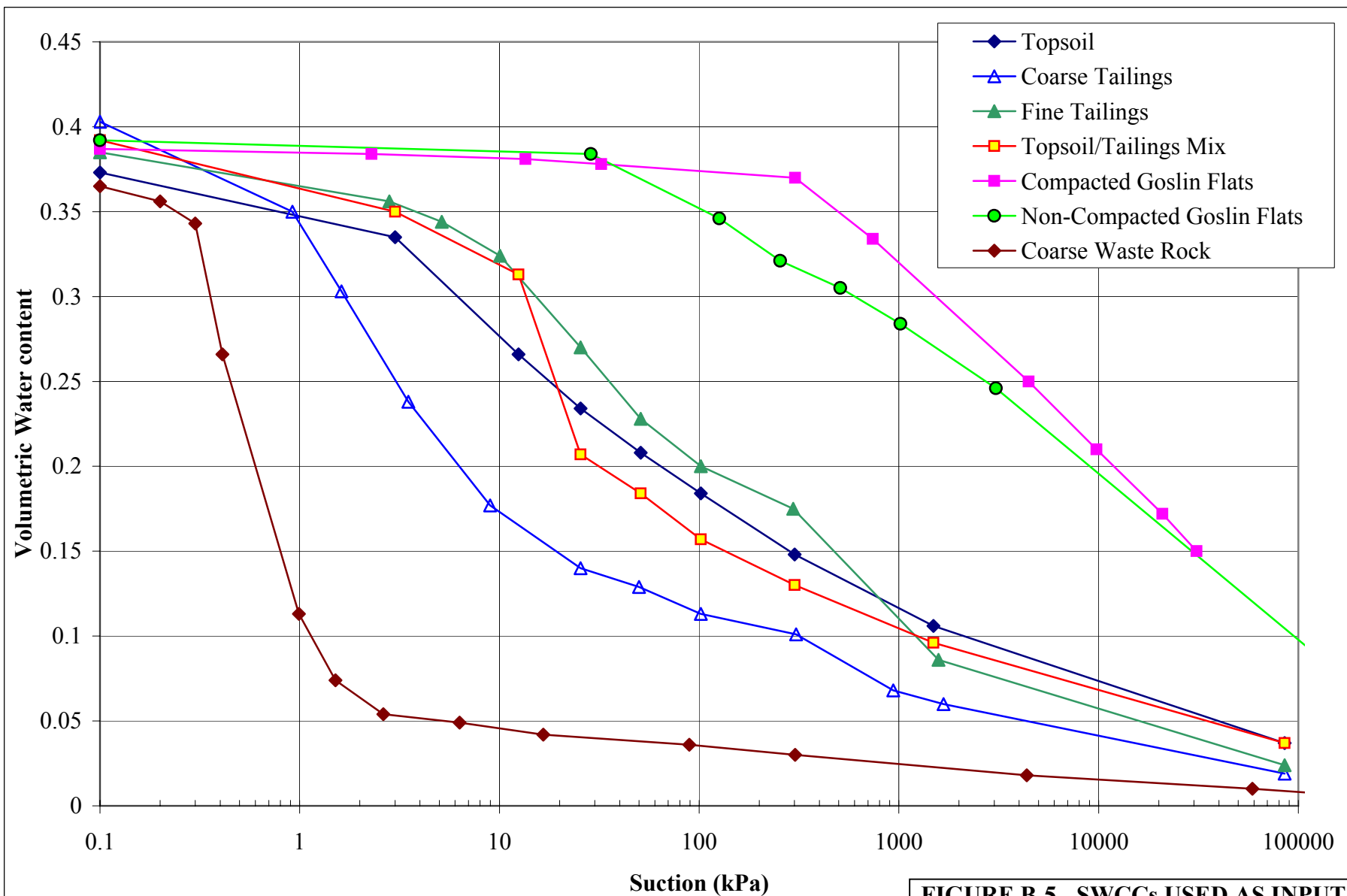
Climate Data

The cover performance is critically dependent on the climatic conditions at the site and care was taken to obtain site-specific climate data to the extent available. SoilCover requires the input of daily values for precipitation, min/max temperature, min/max relative humidity and potential evaporation for the reduced weather data option (Geoslope, 2000).

Table B-7 lists the meteorological monitoring stations and observed climate parameters in vicinity of the Zortman and Landusky Mine sites. The weather stations on the Zortman site (Seven Mile Road) and on the Landusky site (Gold Bug and Sullivan Park) were maintained by Zortman Mining Inc. from 1990-1996 as part of an air monitoring program. However, these stations were of limited use for this analysis due to the short observation period and the fact that only precipitation and total monthly pan evaporation was measured. The other weather stations have been operated for much longer periods of time (in particular at Zortman and Mocassin) by various agencies. The most complete set of climate parameters is monitored at the BLM-Zortman station, which is located in close proximity to the Zortman Mine.

Table B-6 - Summary of Various Cover Scenarios Modeled

Cover Type	Topsoil	Ruby Gulch Tailings	Goslin Flats Material	NAG	Clay	Geosynthetic	Comments
1	12"			36"		GCL	ROD-specified water barrier cover
2	8"	10"		24"		HDPE	Water barrier cover
3	12"			36"		HDPE	Water barrier cover
4	11"	7"		24"	8"		Moisture storage in topsoil, capillary break layer (tailings) and a low permeability clay layer
5	12"			24"	8"		Moisture storage in topsoil with a low permeability clay layer
6	18"		12"				Compacted Goslin Flats material to provide a low permeability layer
7	12"		18"				Uncompacted Goslin Flats material to provide additional water holding capacity
8	36"			variable			ROD-type water balance cover with added water storage potential
9	24"			variable			Moisture storage layer (topsoil) - primarily a growth media cover
10	12"			variable			Moisture storage layer (topsoil) - primarily a growth media cover
11	8"			variable			Lesser water storage layer (topsoil) - primarily a growth media cover
12	18"	6"		variable			Thicker water storage layer (topsoil) with capillary break layer (tailings)
13	8"	10"		variable			Lesser water storage layer (topsoil) with greater capillary break layer (tailings)
14	11"	7"		variable			Moisture storage in the topsoil with a capillary break layer (tailings)
15	12"	7"		variable			Moisture storage in the topsoil with a capillary break layer (tailings)
16	19" (mixed)			variable			May have advantages for revegetation and water storage potential
17	29"	7"		variable			Additional water storage in thicker topsoil layer with a capillary break layer (tailings)



**FIGURE B-5 - SWCCs USED AS INPUT
TO SOIL COVER MODEL**

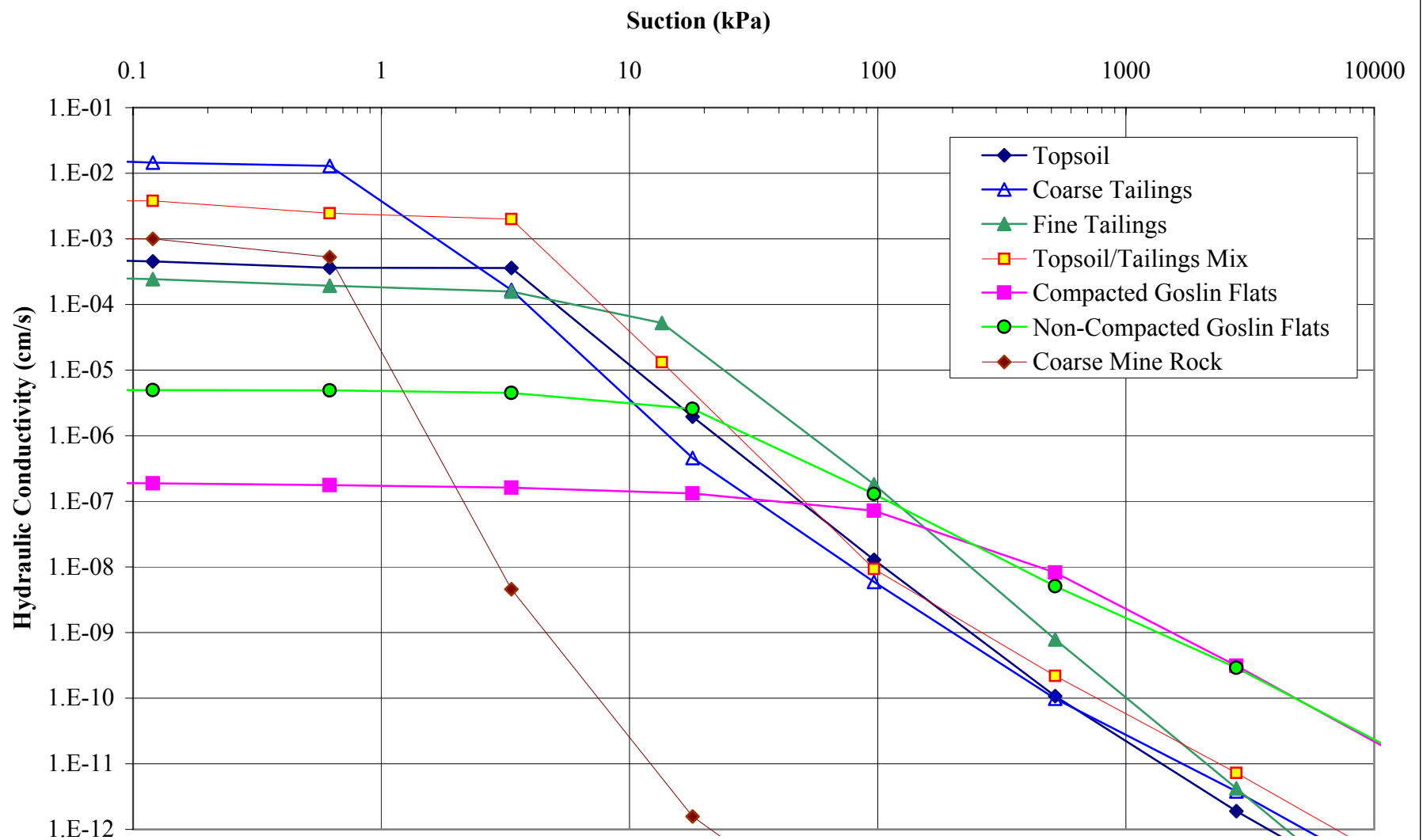


FIGURE B-6 - HYDRAULIC CONDUCTIVITY FUNCTIONS USED AS INPUT TO SOIL COVER MODEL

Table B-8 also shows the monthly total precipitation for the years 1989, 1992, 1993, 1997 and 1998 at selected met stations in vicinity of the Zortman and Landusky Mine sites. The data indicate significant local variations in precipitation. The data suggest that the Landusky site receives on average more precipitation than the Zortman site. The various stations near the Zortman site also showed significant variations both from month to month and year to year. The Seven Mile Rd station received significantly less precipitation than the other three stations near Zortman, likely due to the geographic location. Elevation does not appear to be the dominant factor as the Zortman town site and the Seven Mile Rd stations are at similar elevation yet differed significantly in total annual precipitation.

The climate data also indicate that the early nineties were a relatively wet period with the year 1993 one of the wettest years on record. The year 1989 represents an above-average “wet” year whereas 1992 represents a below-average “drier” year. The slightly above-average “wet” year 1989 and a very “wet” year, 1997 were used for comparative modeling of the various cover alternatives. Years 1992 and 1993 were used for sensitivity runs using the base case cover option to assess the influence of variable climate conditions (in particular precipitation) on cover performance.

Table B-7 - Summary of Meteorological Stations near Zortman-Landusky, Montana.

Name	Zortman (NCDC)	BLM - Zortman (RAWS)	Zortman Site	Landusky Site	Mocassin Exp. Station
Location	Zortman town	near Zortman mine site	Seven Mile Road	(Gold Bug/Sullivan Park)	southwest of Zortman
UTM Coordinates	684,332 E	682,825 E	687,100 E	680,200 E	579,754 E
	5,309,763 N	5,310,365 N	5,306,200 N	5,309,700 N	5,211,036 N
Elevation	3870 ft	4660 ft	3680	5160 ft	4300 ft
Measured Climate Parameters (daily)					
Precipitation	X	X	X	X	X
Temperature		X			X
RH		X			
Pan Evaporization			(monthly only)	(monthly only)	X

Note: Zortman Mine (boneyard) at UTM coordinates 682,700 E and 5,310,800 N

Table B-8. Precipitation Statistics for Various Locations (in inches)

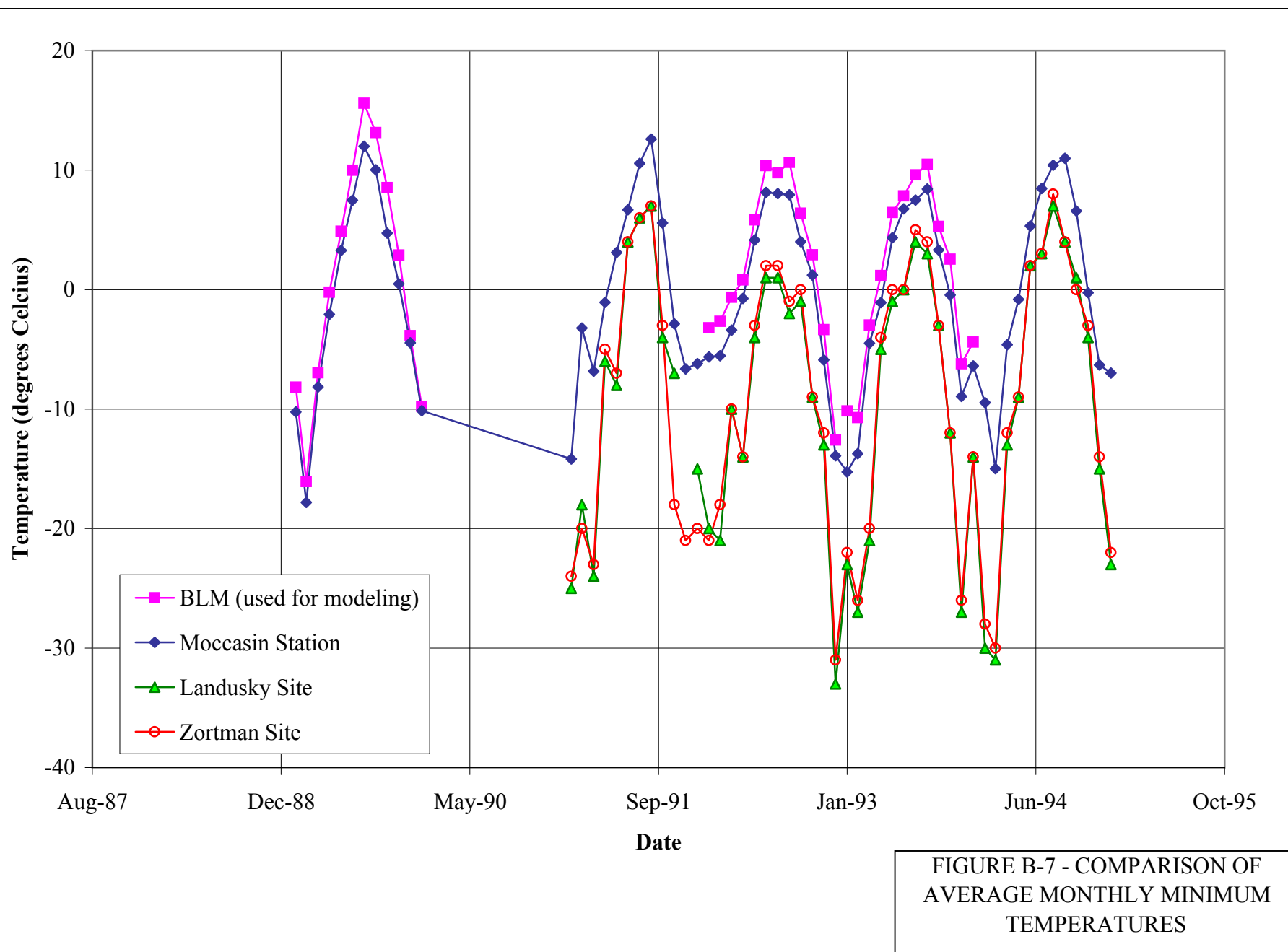
Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL	
														Growing Season	Calendar Year
Zortman town	Long-term Average	0.91	0.52	0.89	1.77	3.09	3.74	2.20	1.80	1.69	0.79	0.44	0.80	15.08	18.64
Zortman town	1989	1.62	1.39	0.74	2.38	6.43	3.32	0.73	4.15	0.53	0.80	1.61	2.94	18.34	26.64
BLM - Zortman		0.09	0.29	0.47	1.85	5.94	4.10	0.66	2.67	0.50	0.76	1.29	1.09	16.48	19.71
Zortman town	1992	0	0.35	1.16	1.05	0.77	5.49	3.54	0.57	1.43	1.08	0.72	0.84	13.93	17.00
BLM - Zortman		0.01	0.16	0.19	1.28	1.05	5.03	3.8	0.91	1.53	1.79	0.55	0.13	15.39	16.43
Seven Mile Rd		0.00	0.14	0.09	0.73	0.16	3.43	2.76	0.50	0.45	0.74	0.55	0.35	8.77	9.90
Landusky (Sullivan Park)		0.92	0.26	0.91	1.26	1.43	5.96	4.09	1.77	1.45	1.66	3.78	2.15	17.62	25.64
Zortman town	1993	0.94	0.73	0.99	1.31	1.55	5.55	10.32	2.82	1.33	1.32	0.65	1.72	24.2	29.23
BLM - Zortman		0.12	0.07	0.89	1.09	1.82	4.66	9.61	3.17	1.46	0.88	0.26	0.40	22.69	24.43
Seven Mile Rd		0.54	0.47	0.10	1.16	1.62	2.86	5.16	1.64	0.72	1.01	0.66	0.20	14.17	16.14
Landusky (Gold Bug)		0.86	0.91	1.55	1.08	1.55	4.27	8.57	3.22	1.62	1.05	1.28	1.55	21.36	27.51
Zortman	1997	0.46	0.33	0.91	2.22	8.22	4.62	2.77	2.36	0.30	1.27	0.12	2.25	21.76	25.83
Landusky (Gold Bug)		0.69	0.38	0.96	1.93	5.16	3.79	2.93	1.50	0.30	1.61	0.10	0.70	17.22	20.05
Zortman	1998	0.80	0.43	2.52	2.82	1.22	8.20	1.25	2.11	0.11	0.93	2.00	1.56	16.64	23.95
Landusky (Gold Bug)		1.06	0.17	1.75	1.95	1.65	7.50	1.45	2.80	0.50	1.05	1.55	1.90	16.9	23.33

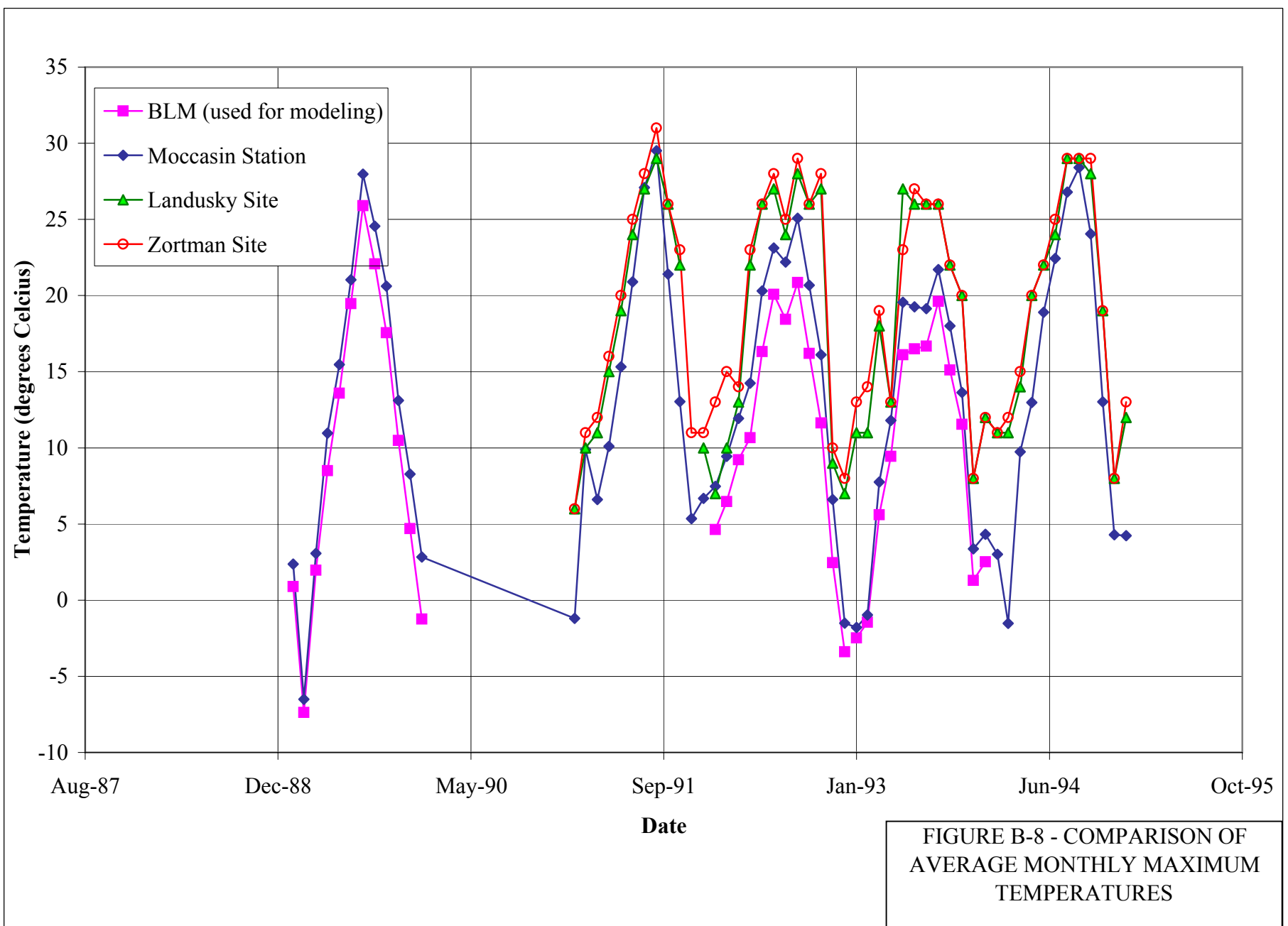
Table B-7 indicates that none of the weather stations in vicinity of the Zortman-Landusky Mine sites monitored all climate parameters required for the SoilCover model. The most detailed set of climate data was available for the BLM-Zortman station. Hence the climate data from this station were selected for the cover modeling analysis. Precipitation observed at the BLM-Zortman station correlated fairly well with the Zortman town site. The precipitation pattern also correlated fairly well with that observed at Landusky (Sullivan Park); however, the total precipitation was significantly lower at the BLM-Zortman station (Table B-8). The precipitation data from the BLM-Zortman station were scaled upward (by 25%) in one of the sensitivity runs to assess the influence of the total amount of precipitation (with same precipitation pattern) on cover performance.

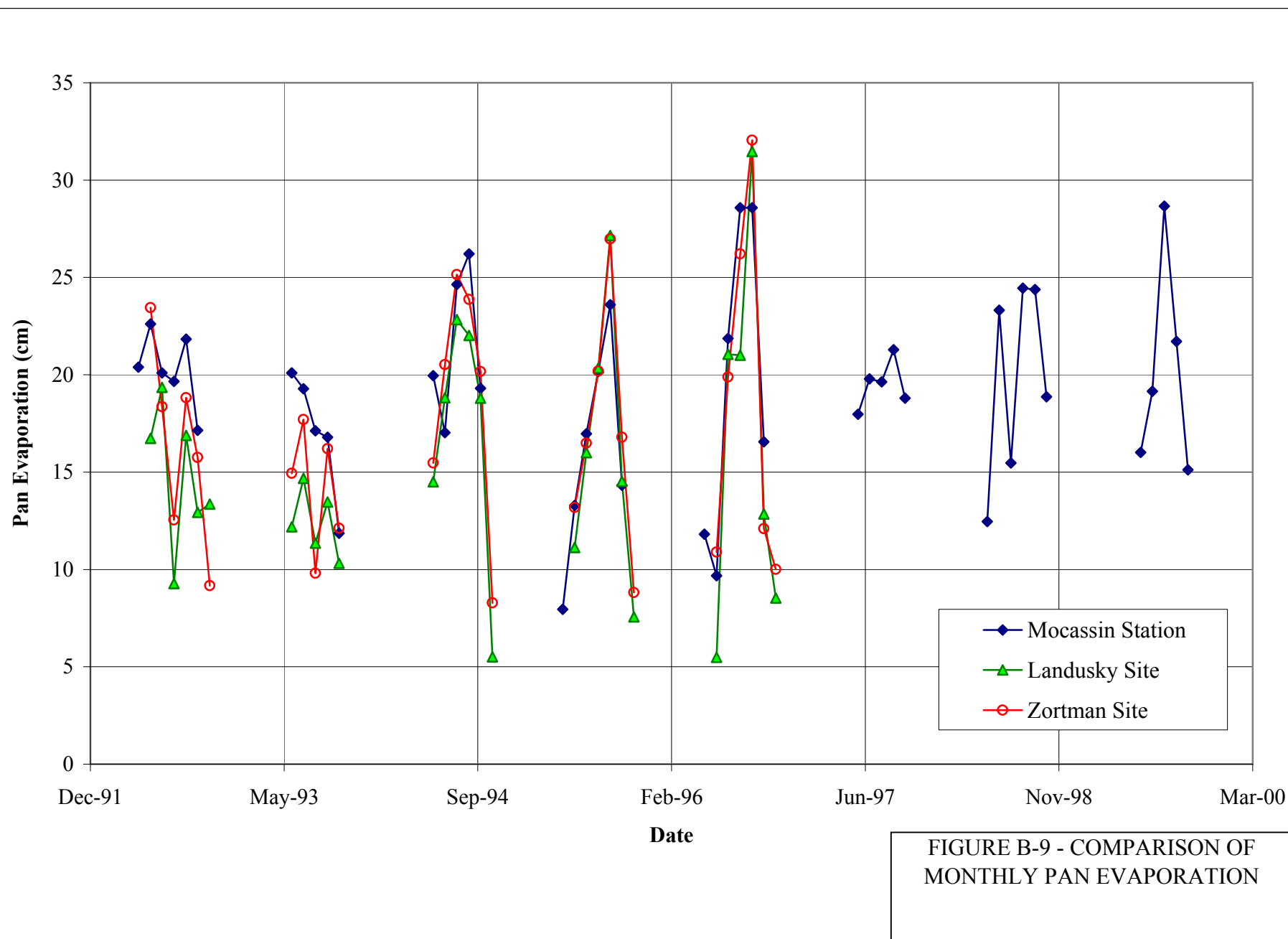
Figures B-7 and B-8 compare the average monthly minimum and maximum temperatures observed at the BLM-Zortman station (with those observed at the Zortman site (“boneyard” at 5080 ft elev.) and the Landusky site (Sullivan Park at 5160ft elev.). The data indicate that all stations experience significant daily and seasonal variations in temperature typical for this continental climate. However, the BLM-Zortman station apparently experiences less dramatic temperature fluctuations than the mine sites, perhaps due to difference in elevation, aspect and/or wind exposure.

The only required climate parameter not measured at the BLM-Zortman station is potential evaporation (or pan evaporation). The nearest weather station with similar climate conditions and a pan evaporation record is the Experimental Mocassin station located about 150 km to the southwest of Zortman-Landusky (Table B-7). Figure B-9 compares the monthly pan evaporation rates for the period 1992 to 1997. The data indicate a generally good agreement of monthly evaporation rates for the years 1994-1996. However, in 1992 and 1993 the monthly pan evaporation rates at Mocassin were typically higher than at Zortman and in particular at Landusky.

While the overall evaporation regime appeared to be similar between Mocassin and Zortman-Landusky, adjustments were required to account for local differences (evaporation rates at Zortman-Landusky appeared to be somewhat lower) and more importantly, to account for temporal (day to day) differences in the weather pattern (relative humidity and amount of precipitation) between the two sites. In particular, precipitation and relative humidity can vary significantly in the short term over a distance of 150 km. For the first phase of SoilCover modeling (including sensitivity analysis) the pan evaporation rates observed at Mocassin were reduced to 0 on those days when the daily minimum relative humidity at BLM Zortman was 100% and by 25% on those days where the daily maximum relative humidity was 100% (RGC Report 075001/5). For the Phase 2 cover performance modeling, carried out in support of the Supplemental EIS, the pan evaporation from Mocassin was set equal to zero for those days where precipitation was observed at BLM Zortman (RGC Report 075001/7). The latter scenario provided a better fit of simulated net percolation (i.e. infiltration through the cover) to observed seepage captured at one of the waste rock dumps for very wet conditions (1997-1998) (see below). The influence of pan evaporation on cover performance was also addressed by way of sensitivity analysis.







Numerical Methods

The details of the numerical methods and assumptions used in the modeling analyses are described in RGC Report Nos. 075001/5 (RGC, July 2000) and 075001/7 (RGC, December 2000). In all simulations the model consisted of the cover layer(s) of variable thickness overlying a 10m thick mine rock profile. The depth of the mine rock profile was chosen sufficiently deep (10m) that this boundary condition had no effect on moisture movement in the upper profile and thus cover performance. All simulations were run for a full calendar year (from January 1st to December 31st) to capture the variable climatic conditions encountered during all four seasons.

Results & Discussion

The cover performance of various cover scenarios is provided in Table B-9. The range in net percolation represents estimates for an ‘average’ year and a ‘very wet’ year. The net percolation typically ranged between 0.1% and 1.0% for water barrier covers; 20% and 50% for a water storage type cover; and, 15% and 40% for the ROD-type water balance cover. Note that the estimates of net percolation through a water barrier cover (using HDPE or GCL) were taken from earlier modeling work carried out in support of the EIS using the HELP model (Woodward Clyde, 1995). All estimates for flat surfaces are directly or indirectly based on simulations carried out using the SoilCover model. All estimates for sloped surfaces are based on 2D cover performance calculations carried out using SEEP/W (see below).

An inspection of Table B9 shows that the net percolation into a water storage type cover and the ROD type water balance covers increases disproportionately from dry to wet years. This behavior is typical for a water storage cover with a finite storage capacity. During drier years, the vast majority of the incoming precipitation can be stored in the storage cover and can be released back to the atmosphere by evapotranspiration between subsequent events. During very wet years, the storage capacity is depleted for much of the year and a significant portion of the incoming precipitation (in particular during intense rainstorm events) can pass through the cover. In addition, wetter years typically exhibit lower potential evaporation rates (due to greater cloud cover) than do drier years thus further reducing the potential of the storage cover to release soil moisture back into the atmosphere. The modeling results of the “average” year 1989 are discussed in more detail below to illustrate the seasonal behavior of a water storage cover.

Figure B-10 shows the cumulative atmospheric fluxes (potential & actual ET, precipitation), the surface flux into the cover, and the net percolation into the mine rock profile for the cover consisting of 11” of topsoil over 7” of tailings. Positive fluxes indicate upward movement of soil moisture (out of the soil profile) and negative fluxes indicate downward movement (into the soil profile). During the early part of the year 1989 (say first 100 days) there was little precipitation and as a result infiltration into the cover was small with no significant percolation into the mine rock profile. The majority of precipitation fell during late spring/early summer (days 115 to 180). In the early part of this wet period, the precipitation was stored in the cover, as indicated by an increase in the cumulative surface flux (towards higher negative values) with no commensurate increase in the net percolation. The first significant net percolation into the mine rock profile

occurred following a period of heavy rain from day 131 to 133. During this three-day period a total of 2.44 inches (62 mm) of precipitation occurred resulting in 1.8 inches (42 mm) of net percolation. The period immediately following this event remained fairly wet allowing for very little depletion of soil moisture in the storage cover, hence additional net percolation into the mine rock profile.

Throughout the wet spring/early summer period the full potential evaporation was realized due to the very wet soil conditions providing ample moisture for evaporation. After cessation of the rain events (after day 185) evaporation quickly depleted all soil moisture available in the storage cover (as indicated by the flattening of the actual evaporative flux curve). Note that the net percolation does not decrease (move towards less negative numbers) indicating that there is no flux from the mine rock profile back into the cover layers. The lack of upward movement from the mine rock profile back into the cover layers is a result of the very coarse nature of the mine rock which causes a capillary barrier to develop between the finer cover layer and the coarse mine rock.

Subsequent isolated rainfall events that occurred throughout the late summer, fall and winter resulted in additional surface fluxes into the cover. However, all of this moisture was stored in the storage cover and did not result in additional net percolation.

Figure B-11 shows the time trends in soil suction (negative pressure) at selected depths in the soil profile. The model simulation indicates that soil suctions in the cover layers remain in the range of 1 to 10 kPa during the recharge periods. However, during the dry summer months soil suctions increase dramatically throughout the cover profile (including the tailings layer) due to the strong evaporative stresses exerted at the soil profile. The increase in suction indicates that the storage cover is drying out resulting in renewed moisture storage capacity for subsequent recharge periods. Note that the soil suctions in the mine rock profile change very little during the summer period indicating that very little moisture is removed from the mine rock back into the cover and to the surface.

Table B-9 - Modeled Cover Performance for Various Cover Scenarios

Topsoil (inches)	Tailings (inches)	Goslin Flats Material	NAG (inches)	Clay	Geosynthetic Barrier Layer	Projected Infiltration Rate (% of Annual Precipitation) (average to very wet year)
12			36		GCL	flat 0.09% - 0.12% ¹
36			variable			flat 14.0 - 42.8
						slope 7 - 21 ²
24			variable			flat 16.4 - 43.6
						slope 12 - 33 ²
12			variable			flat 23.8 - 50.1
						slope 21 - 45 ²
12		18	variable			flat 21-30 ³
8			variable			flat 28.2 - 54.1
						slope 25 - 49 ²
18	6		variable			flat 15.0 - 42.2
						slope 13 - 36 ²
18		12	variable			flat 5-10 ³
8	10		variable			flat 16.6 - 43.3
						slope 14 - 37 ²
11	7		variable			flat 17.8 - 43.8
						slope 15 - 37 ²
8	10		24		HDPE	flat 0.09 - 1.0 ¹
12			36		HDPE	flat 0.09 - 1.0 ¹
						slope 0.09 - 1.0 ¹
11	7		24	8		flat 8 - 15 ²
						slope 8 - 15 ²
12			24	8		flat 10 - 15 ²
						slope 10 - 15 ²
8	24		12			slope 13 - 21 ²

Notes:

All infiltration rates were calculated using the Soilcover model unless otherwise indicated. The estimates for an average year were obtained by using 1989 climate data (and using relative humidity as an index for adjusting pan evaporation from Mocassin). The estimate for a "very wet" year were obtained by using 1997 climate data (and using precipitation as an index for adjusting Pan Evaporation from Mocassin). The following exceptions apply:

- (1) result of HELP modeling performed by Woodward Clyde 1995
- (2) estimates inferred from Soilcover (1D) and Seep/W (2D) model runs for similar cover scenarios
- (3) upper limit (very wet year) represents an estimate (I.e. not simulated)

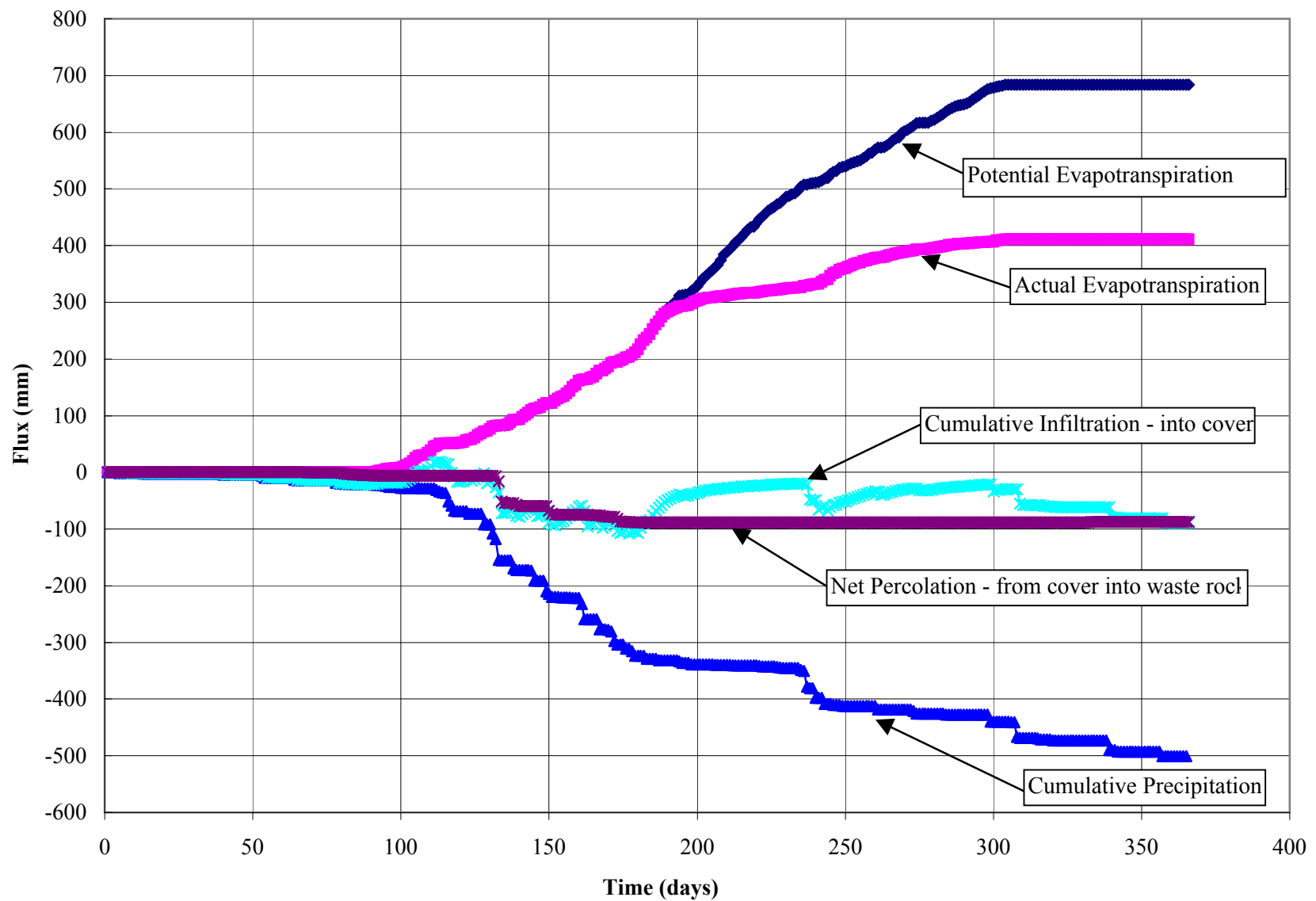


FIGURE B-10 - CUMULATIVE FLUXES AND NET PERCOLATION FOR COVER SCENARIO OF 12" TOPSOIL OVER 7" TAILINGS

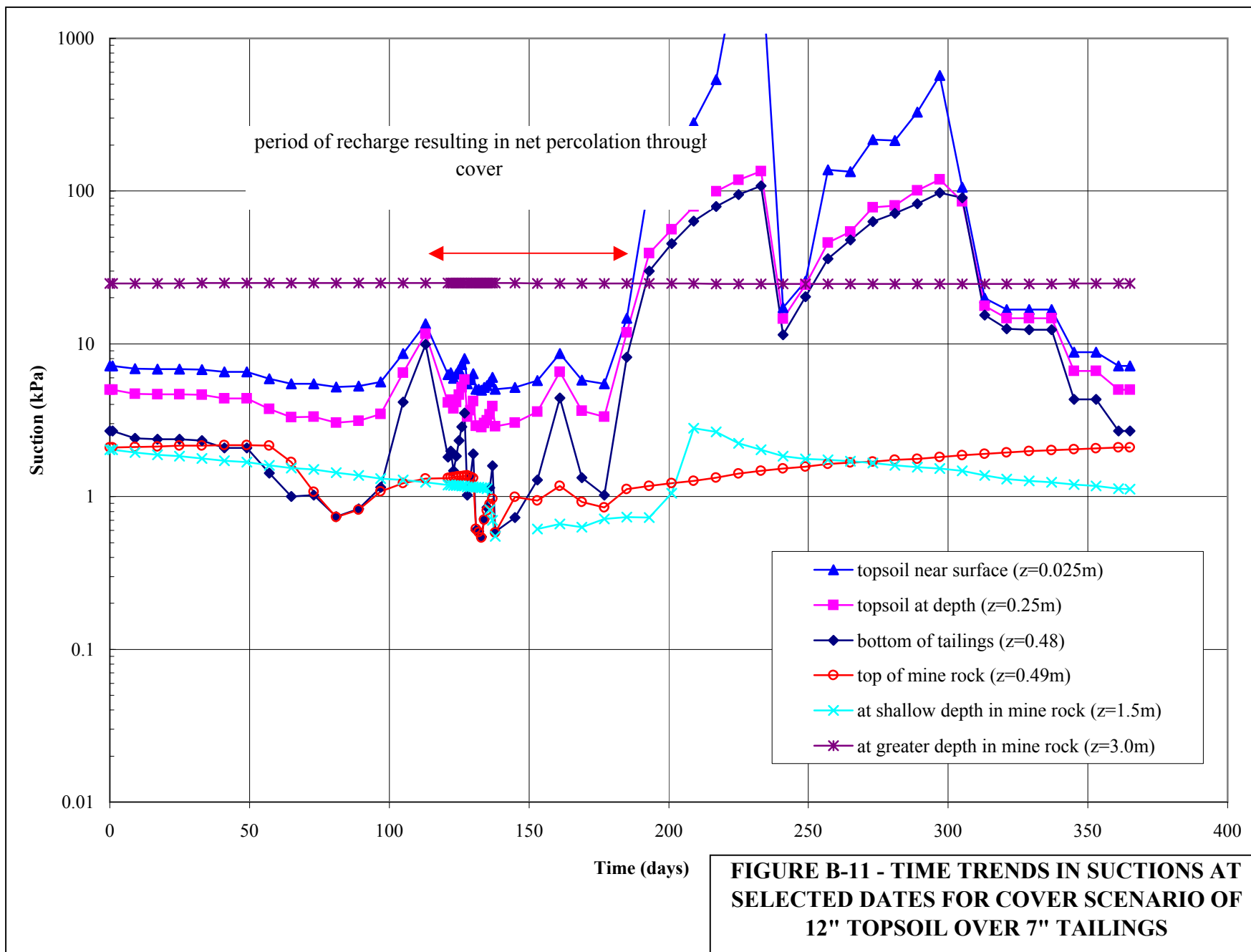


Figure B-12 shows the suction profiles in the upper meter of the soil profile for selected dates throughout the year. For the early part of the year (days 49, 97 and 133) the suctions decrease with depth indicating downward movement of soil moisture. Note the progressive shift of the suction profiles towards the left (lower suctions) indicating higher moisture contents and hence greater fluxes. For the following three dates strong soil suctions develop at the surface (due to evaporation and depletion of soil moisture in the storage cover) resulting in strong upward pressure gradients and upward moisture flux.

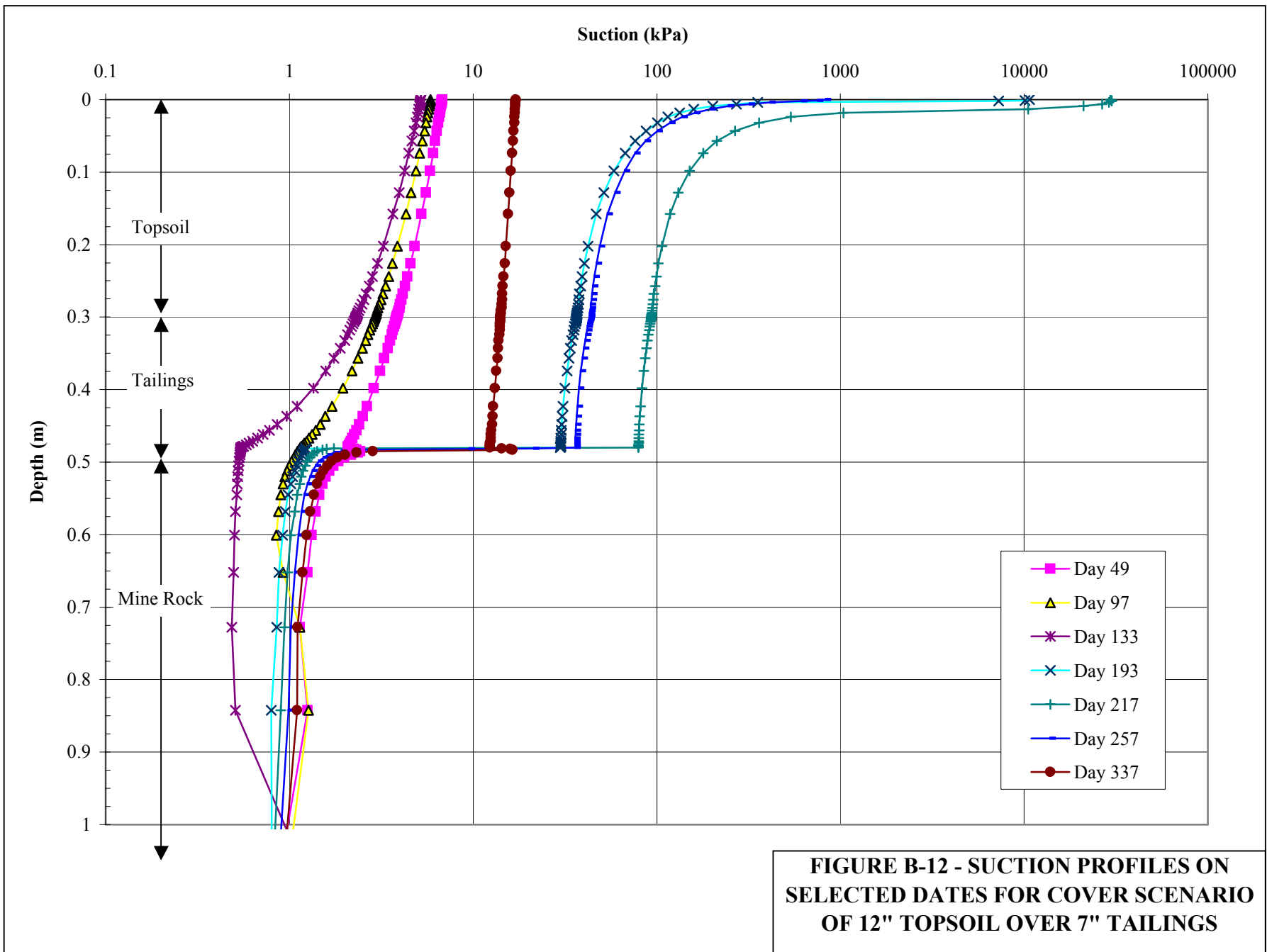
Figure B-13 shows the degree of saturation in the upper meter of the soil profile for selected dates. The degree of saturation is defined as the volume of water divided by the volume of voids (in %). At 100 % saturation the soil is completely saturated. The degree of saturation of the cover profile varies significantly throughout the year with highest values during the very wet spring/early summer period. Note that the cover profile never completely saturates even on days of intense rainfall (day 133).

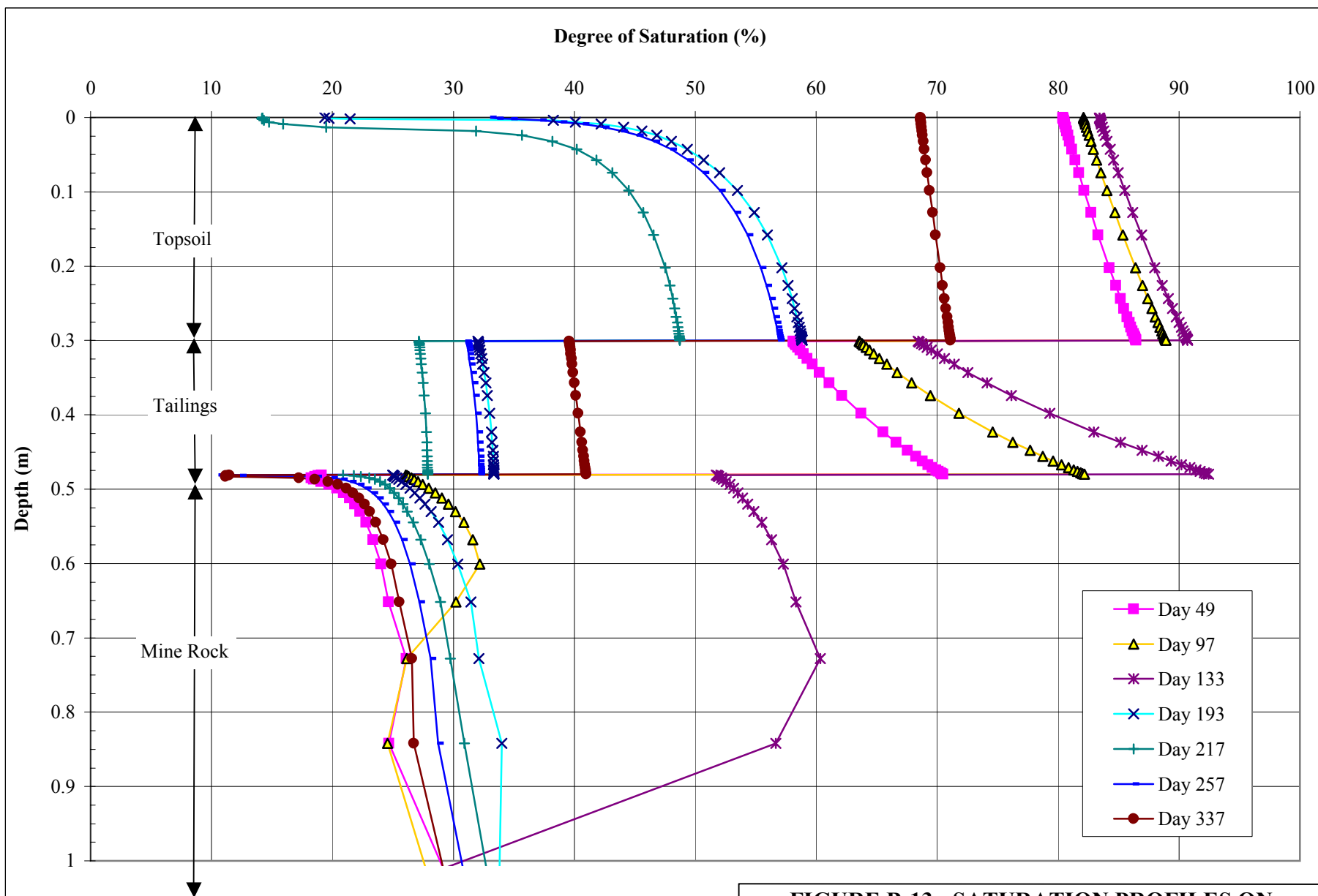
In summary the simulated net percolation for the case of 11 inches of topsoil over 7 inches of tailings was 3.5 inches (88mm) over the calendar year 1989. This is equivalent to 18.0% of the total precipitation for this model year. The majority of net percolation occurred over a relatively short recharge period in late spring/early summer when very intense rain storm events resulted in depletion of all soil moisture storage in the cover layers. The large difference in PSD between the cover layers and the mine rock result in a capillary barrier developing at the boundary between the cover and the mine rock. This capillary barrier prevents upward movement of soil moisture from the mine rock back into the cover layers.

Sensitivity Analyses

Table B-10 summarizes the results of the sensitivity analysis using the cover scenario of 12" of topsoil over 7" of tailings and the "average wet" year 1989 for reference. A total of 14 sensitivity runs were carried out in which various material properties as well as climate parameters were varied within an estimated range of uncertainty. These sensitivity runs were carried out as part of the Phase 1 soil cover modeling (RGC Report 075001/5).

The results indicate that the cover performance (in terms of net percolation) is not very sensitive to the assumed material properties for the cover and mine rock profile (within the estimate range of uncertainty). In contrast, the assumed climate parameters have a strong influence on the simulated cover performance.





**FIGURE B-13 - SATURATION PROFILES ON
SELECTED DATES FOR COVER SCENARIO OF 12"
TOPSOIL OVER 7" TAILINGS**

Table B-10 - Summary of Sensitivity Analyses Using 12" Topsoil - 7" Tailings Cover Scenario.

Run ID	Description	Year	Precip. (inches)	Total Pot. Evap. (inches)	Net Percolation		
					mm	inches	% of Precip
Cover Type: 12" topsoil over 7" tailings							
Run 1m89a	Cover Type - 30 cm (11.8") topsoil, 18 cm (7") tailings, 10 m waste rock (using Kidston Waste Rock) - where both max and min RH is 100%, pan evap=0; where max RH is 100%, pan evap=25% ; use 1989 climate data	1989	19.7	27.0	88	3.5	18%
Sensitivity on Material Properties							
Run 0	as Run1m89a but use SWCC of fine tailings (Z-3) instead of coarse tailings (Z-1)	1989	19.7	27.0	87	3.4	2541%
Run 1	as Run0 except: decrease porosity of topsoil by 15% from 0.373 to 0.317				88	3.4	345%
Run 2	as Run 0 except: decrease topsoil Ksat from 5.6e-4 to 1e-4				87	3.4	17%
Run 3	as Run 0 except: increase topsoil Ksat from 5.6e-4 to 1e-3				111	4.4	22%
Run 4	as Run 0 except: decrease porosity of tailing by 15% from 0.385 to 0.327				85	3.4	17%
Run 5	as Run 0 except: increase tailings Ksat from 2e-2 to 5e-2				87	3.4	17%
Run 6	as Run 0 except: decrease tailings Ksat from 2e-2 to 5e-3				89	3.5	18%
Run 7	as Run 0 except: decrease waste rock Ksat from 1e-2 to 5e-2				76	3.0	15%
Run 8	as Run 0 except: increase waste rock Ksat from 1e-2 to 1e-1				78	3.1	16%
Run 9	as Run 0 except: use Z-84 waste rock in place of Kidston Waste Rock				66	2.6	13%
Sensitivity on Climate Parameters							
Run 10	as Run 0 except: 0.65 of pan evap equivalent to potential evap and decrease evap by 25% (regardless of % RH)	1989	19.7	20.2	120	4.7	24%
Run 11	as Run 0 except: 0.65 of pan evap equivalent to potential evap (did not take changes in RH into consideration)			30.3	39	1.5	8%
Run 12	as Run 0 except: 0.55 of pan evap equivalent to potential evap (take changes in RH into consideration)			25.7	97	3.8	19%
Run 13	as Run 0 except: increase precipitation by 25%		24.6	27.0	183	7.2	36%

The large variation in net percolation for different precipitation rates (average vs very wet year) has been discussed already (see Table B-9). The results of the sensitivity analyses support these findings. Apart from precipitation, the rate of potential evaporation (both in overall magnitude as well as temporal distribution) has an equally strong influence on the total net percolation.

These results of the sensitivity analysis highlight the importance of using representative climate data for cover performance modeling. They also indicate that differences in climate conditions have to be taken into account when extrapolating these model results to the field. For example, the same cover may perform differently at Zortman compared to Landusky due to local differences in climate conditions. Orographic effects also have to be considered when evaluating cover performance. In areas with significant topographic relief the same cover may even perform different depending on the micro-climate conditions (with higher elevation sites typically being less favorable for cover performance than low-elevation sites).

While care was taken to obtain site-specific climate data, some critical parameters (in particular pan evaporation) were not measured on site and were therefore estimated. Hence, there is some uncertainty associated with the modeled net percolation, and some deviation from actual field performance can be expected. There is much less uncertainty, however, when comparing the net percolation for different cover alternatives assuming the same climate conditions.

Comparison of Cover Alternatives

All seventeen alternative cover scenarios were evaluated using the climate data of the “average wet” year 1989. The majority of these simulations were carried out in Phase 1 of the cover performance modeling work (RGC Report 075001/5). Seven of these covers (i.e. those finally incorporated into the various reclamation alternatives) were evaluated in Phase 2 of the cover performance modeling work using both “average wet” conditions (year 1989) as well as “very wet” conditions (year 1997). The latter conditions were evaluated to provide an upper bound on likely net percolation (“worst-case” scenario). The year 1997 was selected for this analysis in order to correlate the modeling results with the site water balance (Spectrum Engineering, 2000e and 2000f).

Table B-9 summarizes the SoilCover modeling results for the various alternative cover scenarios. The net percolation for all cover alternatives varied from a low of 0.09% to 0.12% for the ROD-specified water barrier cover to a high of 28% to 54% for the 8” topsoil cover over NAG. In the following discussion we briefly summarize the performance of the various cover alternatives.

The cover consisting of the mixture of 19” of topsoil/tailings has a seasonal pattern in net percolation similar to that of the cover of 11” topsoil layered overtop of 7” of tailings, i.e. most of the net percolation occurs during the very wet period from day 131 to 180. However, the topsoil/tailings mixture allowed significantly more additional net percolation during the early spring and late fall/early winter. The higher cover fluxes resulted in generally wetter conditions in the mine rock profile early in the year as demonstrated by overall lower suction values and a higher degree of saturation (see RGC Report No. 075001/5, RGC July 2000). The higher annual

net percolation is a result of the overall poorer moisture retention capacity of the topsoil/tailings mixture relative to the layered topsoil/tailings profile.

The cover type with a thicker topsoil layer (29”) over 7” of tailings resulted in an increased storage capacity of the thicker topsoil layer which “buffers” the first very intense rainstorm events resulting in much reduced net percolation during these first days of the recharge period. However, once this additional storage demand is met subsequent rain events result in similar net percolation as was observed in the thinner cover types. The thicker topsoil layer results in much more uniform moisture conditions in the underlying tailings as evidenced by much smaller variations in suction and degree of saturation throughout the year.

The water storage cover consisting of 12” of topsoil overlying 18” of non-compacted Goslin Flats material does not show the steep “breakthrough” of net percolation in response to specific rainfall events observed for the simpler covers described above. Instead, the net percolation occurs more steadily throughout the wet season (including winter and early spring) (RGC, July 2000).

The relatively high net percolation of this type of cover appears counterintuitive at first but can be explained by comparing the unsaturated properties of the various cover materials. During the recharge period, the soil suction in the Goslin Flats material (near the cover-mine rock interface) typically ranged from ~1 to 20 kPa. In this suction range, the hydraulic conductivity of the Goslin Flats material is nearly constant ($\sim 5 \times 10^{-6}$ cm/s) whereas the hydraulic conductivities of the other cover materials and the coarse mine rock decline significantly (Figure B-6). During intense rainstorm events when the entire soil profile approaches saturation and suctions fall to very low values (<10 kPa) the Goslin Flats material has the lowest hydraulic conductivity and limits the rate of net percolation. In contrast, during less intense wet periods and dry periods the hydraulic conductivity of the Goslin Flats material is indeed greater than that of the coarser cover materials resulting in greater net percolation.

The cover that includes the non-compacted Goslin Flats material remains near saturation for most of the year. The high degree of saturation throughout the year is a result of the high AEV of this silty material. The very limited reduction in soil moisture during the drier summer/fall periods indicates that the Goslin Flats material does not provide a good storage capacity for the simulated range in soil suction for 1989.

The cover with the compacted Goslin Flats layer (i.e. 18” of topsoil overlying 12” of compacted Goslin Flats material) shows a very small, but steady increase in net percolation throughout the wet spring/early summer period with essentially short-term fluctuations due to intense rainstorm events. Due to the low hydraulic conductivity of the barrier layer and the limited storage capacity in the overlying topsoil, the cover reached full saturation on several occasions throughout the year resulting in significant surface runoff (total of 2.7 inches or 68 mm).

The compacted Goslin Flats material remained very close to saturation throughout the year, however, field experience has shown that it is very difficult to maintain saturation in fine-grained water barrier layers in semi-arid climates such as at Zortman, at least in the long term.

Figure B-14 compares the cumulative net percolation rates for the above six cover types. This figure demonstrates the importance of the very intense rainfall periods (in particular on day 133) on the net percolation for all water storage covers. Only the cover with the compacted clay layer shows no immediate response (in terms of increased net percolation) in response to individual rainfall events. The success of a water storage type cover in controlling net percolation depends significantly on the distribution of rainfall throughout the year. The rainfall conditions for the 1989 calendar year (i.e. an “average wet” year) were not favorable for a storage cover in that a very heavy rainfall event (2.44 inches in 3 days) followed a very wet spring which had depleted most of the available storage. A review of the precipitation statistics for the Zortman-Landusky area suggests that this pattern is quite common (see Table B-8). The model results indicate that the cover thickness of a water storage cover would have to be significantly greater than 36 inches to reduce the net percolation to levels similar to those predicted for a cover with a compacted clay layer. This statement assumes that the identified materials would be used and that the modeled material properties are applicable.

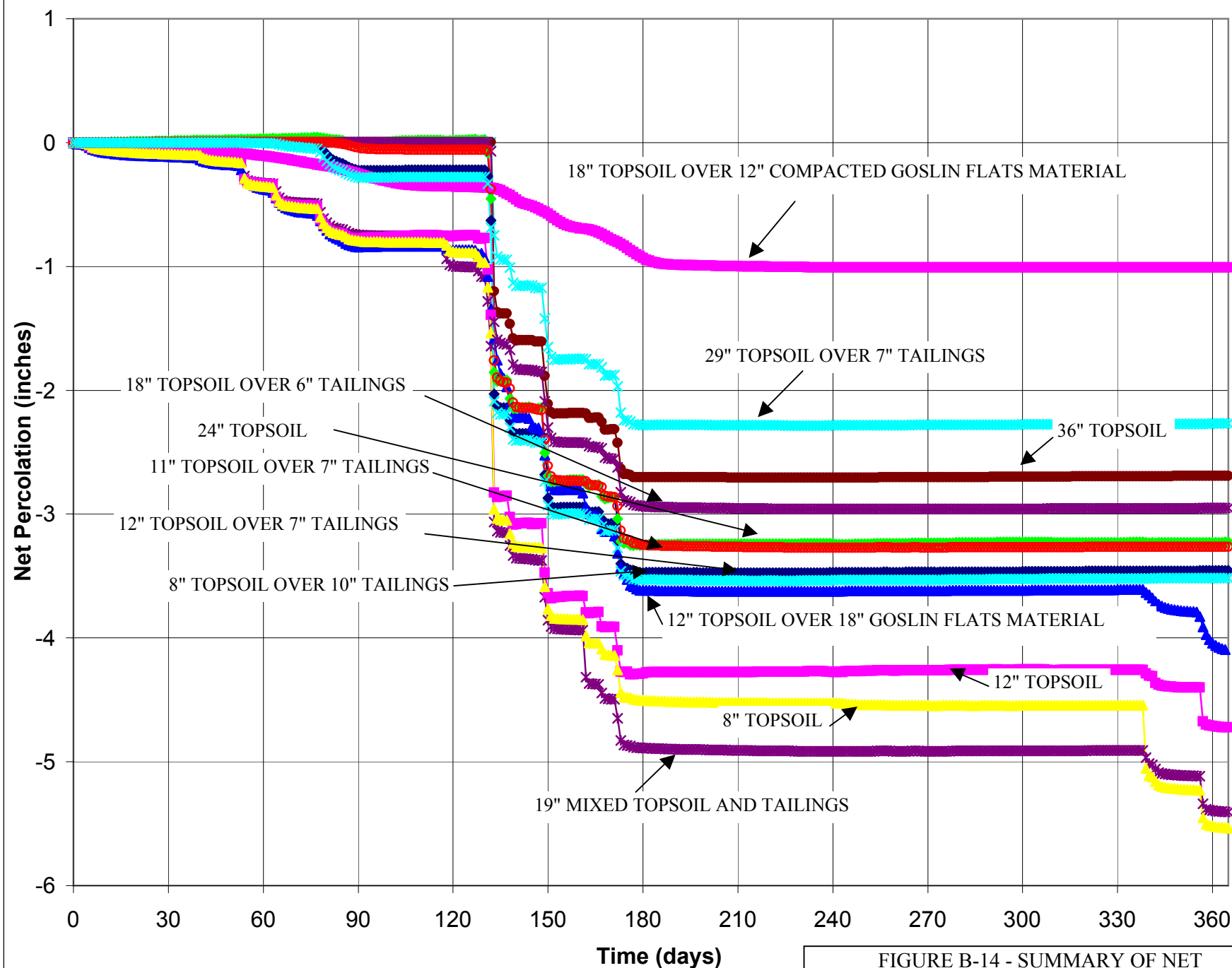


FIGURE B-14 - SUMMARY OF NET PERCOLATION FOR VARIOUS COVER TYPES

Comparison of Soilcover Modeling and Water Balance Calculations

Spectrum Engineering has developed a water balance for the Zortman and Landusky Mine sites based on a review of climate data, site conditions and water collected at various discharge points (streams and/or collection points of leach pads) (Spectrum Engineering, 2000e and 2000f). Of particular interest for comparison with the cover modeling results is the water balance developed for the Carter Gulch capture system. The Carter Gulch system captures drainage from the Alder waste rock (foot print area of about 19.3 acres), which was covered with 0.5-3 ft of topsoil. Note that the total drainage area at the collection point is estimated to be 38.7 acres, i.e. the waste rock dump represents about 50% of the total drainage area.

Over the period October 22nd 97 to March 31st 1999 a total of 51 inches of precipitation fell (at the Zortman gage) (Spectrum Engineering, 2000e). Over the same time period a total equivalent of 27 inches or about 53% of the total precipitation) were collected in the Carter Gulch capture system. These observations suggest that the net percolation through a water storage cover (using topsoil) may be significantly higher than was simulated using SoilCover in the Phase 1 modeling study (with estimates ranging from 6-28% depending on cover thickness and climate conditions).

Some of this discrepancy can be readily attributed to the amount of precipitation that fell during the observation period. The observation period for the water balance study (10/97 to 03/99) was very wet with total annual precipitation in the order of 25 inches per year. Among the model years simulated in the Phase 1 SoilCover modeling the model year 1993 is most comparable to these climate conditions with 24.4 inches total precipitation. The net percolation for the model year 1993 was simulated to be 28% of total precipitation for a cover of 12" topsoil overlying 7" tailings (RGC Report 075001/5). However, a direct comparison of the two estimates (53 vs 28%) is still not possible since the distribution of precipitation throughout the year, which undoubtedly influences net percolation, differed between 1993 and 1997.

For the Phase 2 of the cover performance modeling, which was aimed at assessing cover scenarios which were finally incorporated into the various reclamation alternatives, the observation period 1997-1998 was modeled in order to provide a direct comparison to the water balance estimates of net percolation through already placed cover systems (RGC Report No. 075001/7). Sensitivity analyses carried out earlier (see Table B10) had indicated that the model parameters most significantly influencing the rate of net percolation are (i) precipitation and (ii) pan evaporation. In the Phase 2 Soilcover modeling the same precipitation records as for the water balance study (i.e. from Zortman site) were used. Hence the only "unknown" parameter was pan evaporation which was adjusted to provide a reasonable fit with the observed capture rate in the Carter Gulch capture system (see RGC Report 075001/7 for details). Sensitivity analyses indicated that a reasonable fit with the observed discharge could be obtained by using pan evaporation rates measured at the Mocassin station for those days when no precipitation occurred and assuming no evaporation for the days where precipitation was recorded at Zortman. Using these adjusted pan evaporation rates and 1997 climate data the net percolation for a 24-inch cover consisting of topsoil

was simulated to be 43.6% (RGC Report 075001/7). This percolation rate was still somewhat lower than the observed capture rate (53%). However, in light of the complexity in the natural processes controlling net percolation through a cover system as well as uncertainty in both approaches to estimating the rate of net percolation, the two estimates of net percolation were judged to be in good agreement. Hence, all remaining cover simulations for very wet conditions (i.e. 1997, see upper bound of projected net percolation rates in Table B-9) were carried out using the same approach (i.e. adjusting Mocassin evaporation rates by Zortman precipitation).

Infiltration rates may be higher than those modeled due to channelized flow through root holes and/or other macropores that result in water “by-pass” of the cover layer resulting in direct infiltration into the leach pad. The sharp peaks observed in the hydrographs of the capture systems shortly (several days) after very intense rainstorms support this contention (see Spectrum 2000e and 2000f). Surface ponding during these intense events would facilitate the development of channelized flow through “macropores” in the cover. This type of flow (called Non-Darcian, or turbulent flow) in macropores cannot be simulated with the SoilCover model;

Similarly, if the covers have been placed with little or no quality control and/or are eroded over time (in particular along steep slopes) resulting in very variable cover thickness, significant preferential infiltration may occur in those locations with very little cover (in particular if encountered along a surface runoff pathway). Also, there may be some run-on and/or groundwater discharge in specific drainage areas resulting in a higher seepage collection compared to percolation through the cover.

1.04 COVER PERFORMANCE ON SLOPED SURFACES

Modeling Approach

In the previous analyses it was assumed that the soil cover is placed on a flat (or nearly flat) surface resulting in essentially vertical infiltration. However, a significant proportion of the surface area of the mine rock dumps and leach pads at the Zortman-Landusky Mine sites represent slopes. The finite-element code SEEP/W was used to assess the performance of a water storage cover on such sloped surfaces. SEEP/W is commercially available through GEOSLOPE in Calgary, Alberta, and simulates two-dimensional saturated and/or unsaturated flow using Darcy’s Law (Geoslope, 1994).

To evaluate the cover performance on the slopes, it was assumed that the mine rock piles would be re-sloped to 3:1 prior to cover placement. The maximum slope length was assumed to be 150 ft with an optional road (or drainage ditch) that was “cut” into the slope one-half the way up between the base and the top. The purpose of the road would be to break the slope length (for erosion protection) and to allow drainage of moisture moving down-slope in the storage/drainage layer.

Numerical Methods

Figure B-15 shows the model geometry and boundary conditions for the case with a road (drainage ditch) cut into the cover at mid-slope. Note that the erosion layer (consisting of durable oxidized mine rock or other coarse material) was not included in the finite element model. The coarse nature of this material would not have a significant effect on cover infiltration and/or movement of soil moisture within the cover layer.

A head boundary of pressure equal to 0 KPa was applied at the toe of the slope just beneath the cover (Figure B-15). This base boundary is typical of what may be experienced in the field and it has been used successfully in other slope seepage modeling analyses carried out. In SEEP/W the surface flux at the top of the cover has to be specified by the user (SEEP/W is not capable of calculating the surface flux from atmospheric conditions as does SoilCover).

As a first approximation the surface flux applied on the slope was assumed to be equal to the surface flux (i.e. precipitation minus actual evaporation) computed by SoilCover. In order to reflect “average recharge conditions” the yearly surface flux of about 150mm was applied over 8 months to create a slightly “wetter” than normal top flux.

In Phase 1 of the cover performance modeling several precipitation events were simulated to assess cover performance (in particular whether the capillary break is maintained) for wet to very wet conditions. The SoilCover precipitation data was scanned for the worst-case “wet” periods. For the data provided, there were two periods of time where between 50 and 60 mm of rain fell over a 5 day period. The rain periods were followed by periods of drying, or a net negative evaporative flux. Based on these ranges, the SEEP/W was set up to various sensitivity analyses.

In Phase 2 of the cover performance modeling the seasonal behavior of a sloped soil cover was evaluated. For this purpose the daily infiltration values calculated by SoilCover for the growing season of 1989 (i.e., days 120 – 190) were used as (daily) surface flux boundary conditions and the SEEP/W model was run in hourly time steps.

Average Recharge Conditions

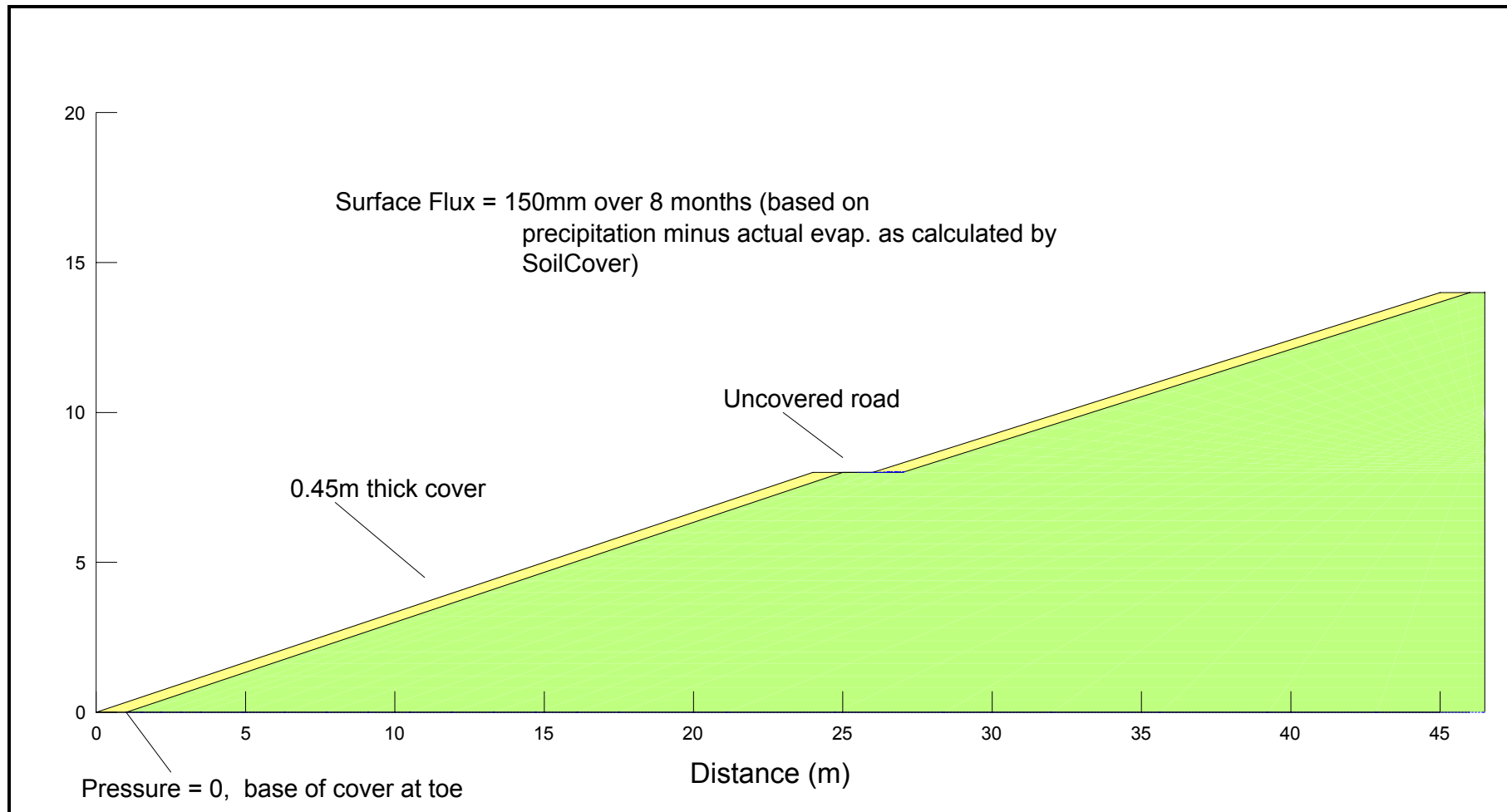
Figure B-16 shows the model results for average recharge conditions (150 mm/ 8 months) for the case where a road (or drainage ditch) is present at mid-slope. This figure also shows the pressure profile (in m pressure head) for the entire slope after 8 months. The velocity flux vectors are plotted in proportion to the flux indicating that the vast majority of flow occurs down slope in the cover layer only. As the length of the slope increases down from the top (i.e., longer infiltration surface) the size of the flux vectors increase but there is no positive pressure build up in the cover. However, at the point where the cover is intersected

by the road, there is evidence that a zero pressure point exists. This would indicate that there is open seepage at this point in the slope.

Figure B-17 shows the model results for the same average (low-intensity) recharge conditions but for the case of a continuous 150ft long slope (no road or drainage ditch is present). Again the pressure head is shown at the end of 8 months. Again, the flux vectors are contained within the cover indicating that all surface flux travels in the sloped storage/drainage layer with no appreciable net percolation through the cover and into the mine rock profile.

Precipitation Events

Figure B-18 shows the pressure profile and flux vectors immediately following the mid-intensity precipitation event (25mm over a three-day period). As for the average recharge conditions, all flux vectors remain in the cover layer and there is no evidence of pressure build up in the bottom end of the cover suggesting that the capillary break between the cover and the mine rock profile remained effective. Other analyses using variable precipitation events (see RGC Report No. 075001/5; RGC, July 2000) also suggest that little net percolation through the cover on the sloped surfaces would be expected when a capillary break is utilized in the cover. In other words, the net percolation along the sloped surfaces could be significantly reduced (compared to flat surfaces) provided a storage/drainage layer is used as cover material that results in the development of a capillary barrier at the interface of the coarse mine rock and the finer-grained cover layer.



**FIGURE B-15 – MODEL GEOMETRY
FOR 150 FT LONG SLOPE WITH ROAD
AT 75 FT DISTANCE**

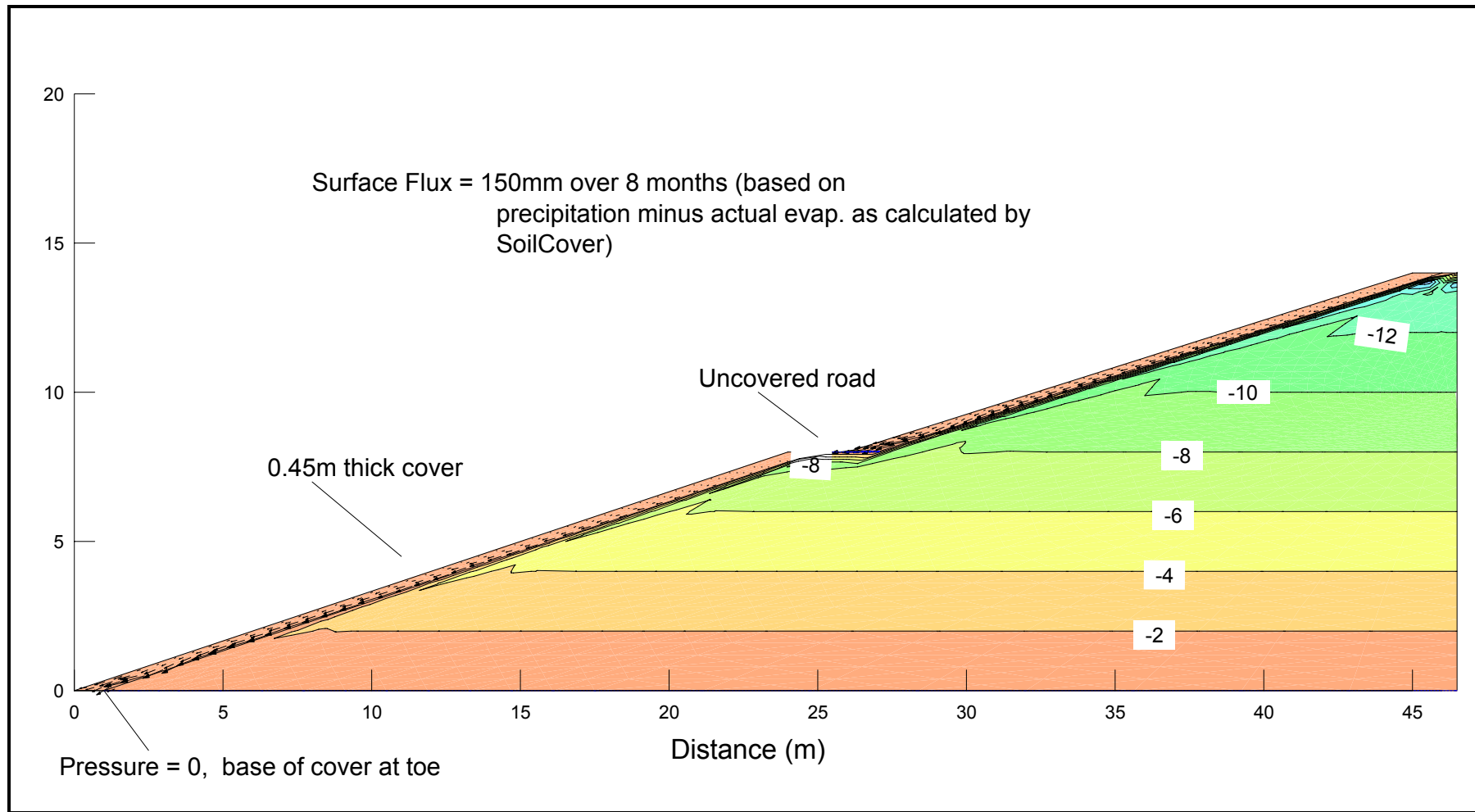
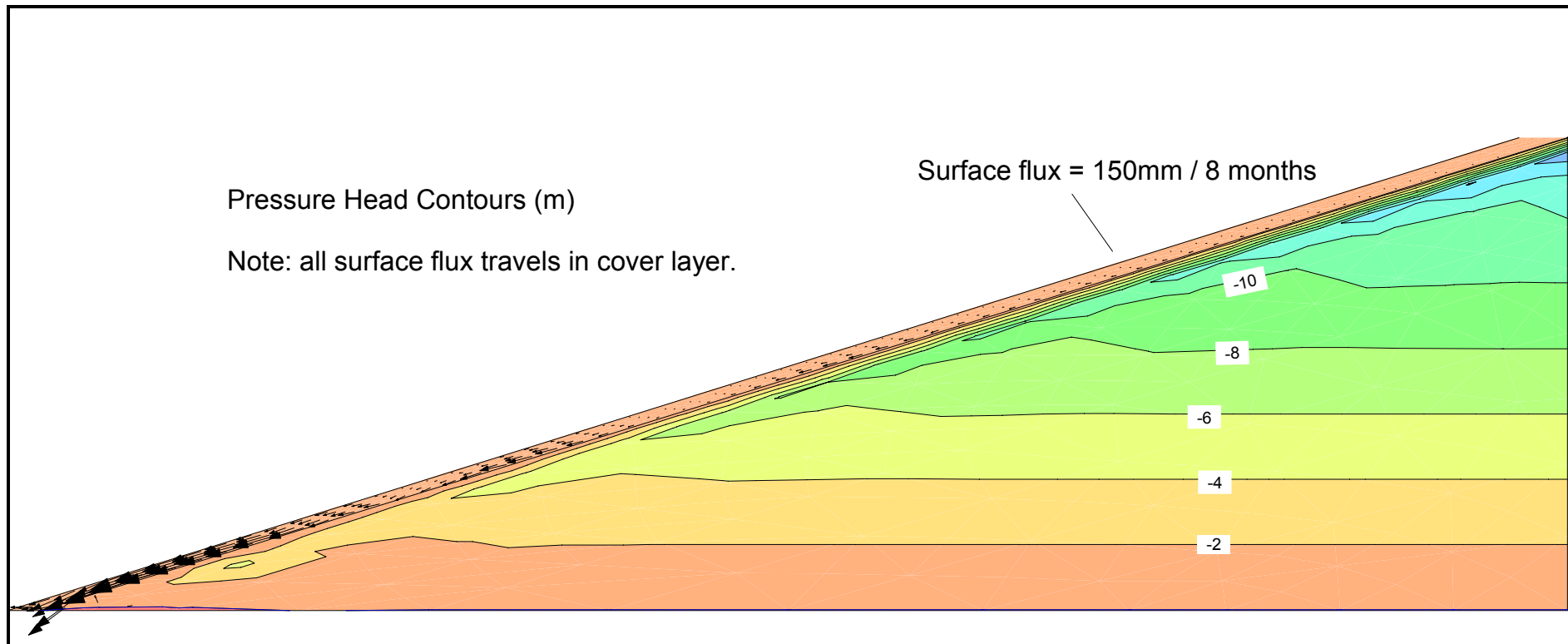


FIGURE B-16 – SIMULATED PRESSURE HEADS AND FLUX VECTORS AFTER 8 MONTHS FOR AVERAGE SURFACE FLUX CONDITIONS (6" OVER 8 MONTHS) ON 150 FT LONG SLOPE WITH ROAD AT 75 FT DISTANCE.



**FIGURE B-17 – SIMULATED PRESSURE HEADS AND
FLUX VECTORS AFTER 8 MONTHS OF AVERAGE
SURFACE FLUX CONDITIONS ON 150 FT
CONTINUOUS SLOPE (NO ROAD)**

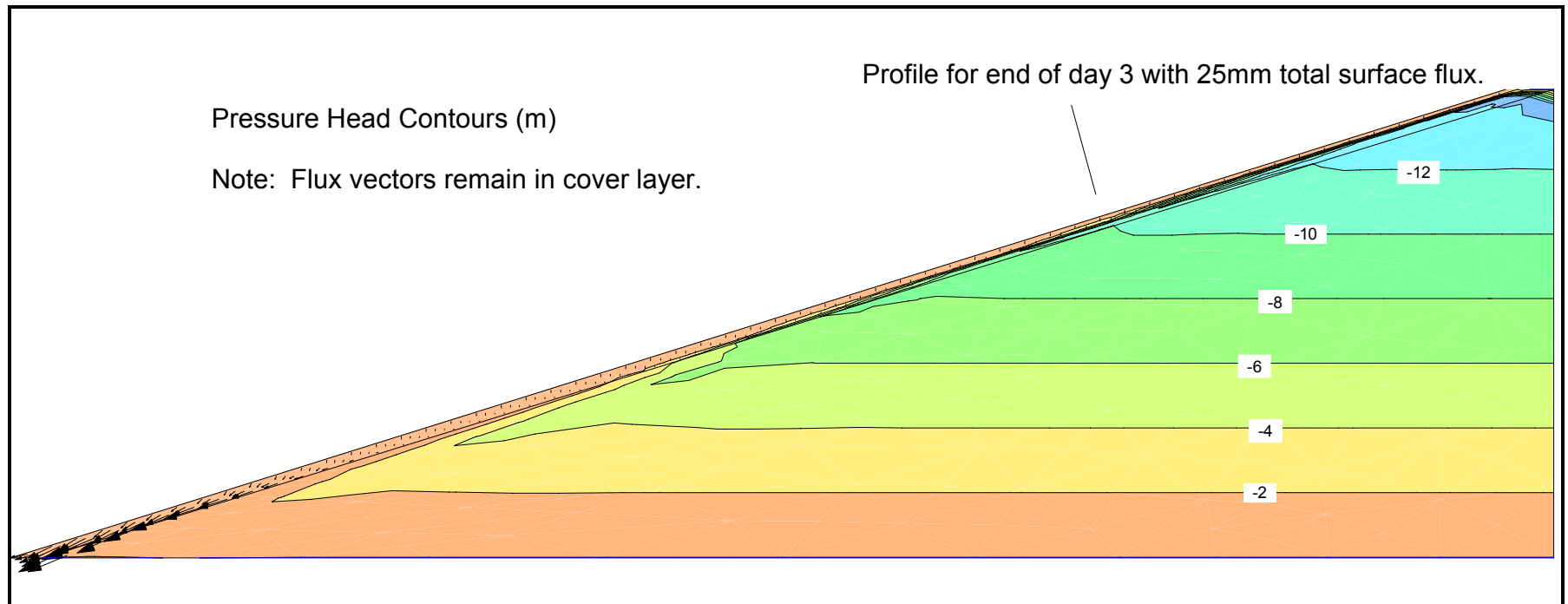


FIGURE B-18 – SIMULATED PRESSURE HEADS AND FLUX VECTORS AFTER 3 DAYS, MID-INTENSITY PRECIPITATION EVENT (1" OVER 3 DAYS) ON 150 FT LONG CONTINUOUS SLOPE

Seasonal Behavior

In Phase 2 of the cover performance modeling the seasonal behavior of a water storage cover (24 inch topsoil) over a re-sloped waste rock surface (3H:1V) was evaluated using a transient analysis with daily inputs of surface infiltration. SEEP/W is not capable of calculating the surface flux (precipitation-actual ET); instead the daily surface fluxes calculated with SoilCover for a 24-inch topsoil cover (on a flat surface) were used as surface flux boundary conditions. The model period covered days 120-190 of the “average wet” year 1989. SoilCover modeling indicated that this period of late spring/early summer generates most of the annual net percolation.

Figures B-19 and B-20 show the moisture retention characteristics (soil water characteristic curve, SWCC) and the hydraulic conductivity functions for the cover material (“topsoil”) and the default mine rock (“waste rock”), respectively. Figure B-21 summarizes the results of the SEEP/W cover modeling analysis (assuming the default mine rock properties) showing cumulative fluxes of infiltration, lateral flow within the cover, and vertical flux into waste rock. Note that the infiltration flux is an input to the SEEP/W model (i.e. an output from the SoilCover model). The lateral flow within the cover represents the flux of water flowing within the soil cover (parallel to the slope face) and emerging at the toe of the covered mine rock pile. The vertical flux into waste rock represents the net percolation into the mine rock (expressed as a unit flux over the entire slope length of 100 ft).

Figure B-21 illustrates that the vast majority (>95%) of infiltrating water is moving laterally within the cover (parallel to the slope) and exits at the toe of the mine rock pile without entering the mine rock. In other words the interface between the finer-grained topsoil and the coarse mine rock represents a very effective capillary break which inhibits vertical movement of soil moisture into the rock pile. Note that during most of the modeled time period (days 12-62) the infiltration is greater than the lateral flux out of the base of the cover, i.e. the cover stores incoming precipitation. In subsequent days the cumulative infiltration drops below the lateral flux out of the base of the cover, i.e. the soil moisture stored within the cover is depleted due to evapotranspiration. In these periods of negative surface flux (i.e. evapotranspiration dominates over precipitation) there is no flow out of the base of the cover (Figure B-21).

Note that these 2D cover modeling results are not consistent with field observations in capture systems from Carter Gulch and other leach pads (which are predominantly sloped rather than flat). As mentioned earlier a water balance analysis of the captured flows suggest a rate of net percolation in the order of 50% of precipitation. In contrast the 2D modeling results would suggest that, if a capillary break effect was present, the net percolation into the covered mine rock pile on sloped surfaces should be very small (i.e. less than say 5% of precipitation). However, the capillary break effect is known to be very sensitive to material properties and a high quality control during construction (in terms of materials used and cover thickness/continuity) is required to ensure proper functioning of such a cover.

In order to illustrate this sensitivity the same cover scenario was rerun assuming a somewhat finer waste rock was present in the rock pile. The finer mine rock used for this sensitivity run is shown in Figures B-19 and B-20 (labeled “interface soil”). Note that the moisture retention characteristics of this hypothetical, finer mine rock are well within the range of properties of mine rock observed at other mines (see e.g. SWCC data for samples from Golden Sunlight, Montana, plotted in Figure B-19 for comparison).

Figure B-22 summarizes the results of this sensitivity run. It is seen that the presence of a finer-grained mine rock greatly reduces the efficacy of a capillary break between the topsoil and the mine rock. In this scenario the amount of lateral flow (within the soil cover) is greatly reduced and slightly more than 50% of all infiltration occurring during the recharge period (days 12-62) percolates into the waste rock.

The 2D modeling results suggest that a capillary break may form along the interface between the finer-grained cover material (topsoil) and the coarse mine rock. This capillary break has the potential to greatly reduce the net percolation on a slope face where the incoming infiltration can drain laterally (parallel to the slope) within the soil cover. However, the efficiency of the reduction in net percolation is very sensitive to the material properties, the cover thickness and the quality control exercised during construction of the soil cover. One of the greatest concerns with the reliance on a capillary break layer is the long-term performance. With time, fines can be expected to move from the cover layer into the upper profile of the coarse mine rock resulting in a deterioration of the capillary break effect. In general, the use of a geofabric placed between the cover layer and the mine rock would greatly facilitate initial placement of the soil cover and would prevent entrainment of finer particles into the mine rock (at least for the life time of the geofabric). In addition, erosion of the topsoil may result in a breakdown of the capillary break effect, in particular if relatively thin covers are utilized (18 inches or less).

Based on the 2D modeling results and recognition of the limitations in implementing/maintaining a capillary break in the field, the following general guidelines were applied for estimating the rate of net percolation on a sloped surface covered with a finer-grained soil layer (c. Table B-9):

- Assume 50% reduction in net percolation for sloped surfaces if geofabric is placed between cover layer and mine rock;
- Assume 25% reduction in net percolation if a thick soil cover (24” or greater) is placed on mine rock;
- Assume 10% reduction in net percolation if a thick soil cover (24” or greater) is placed on mine rock;
- Assume 15% reduction in net percolation if a layered topsoil/tailings cover is placed on mine rock.

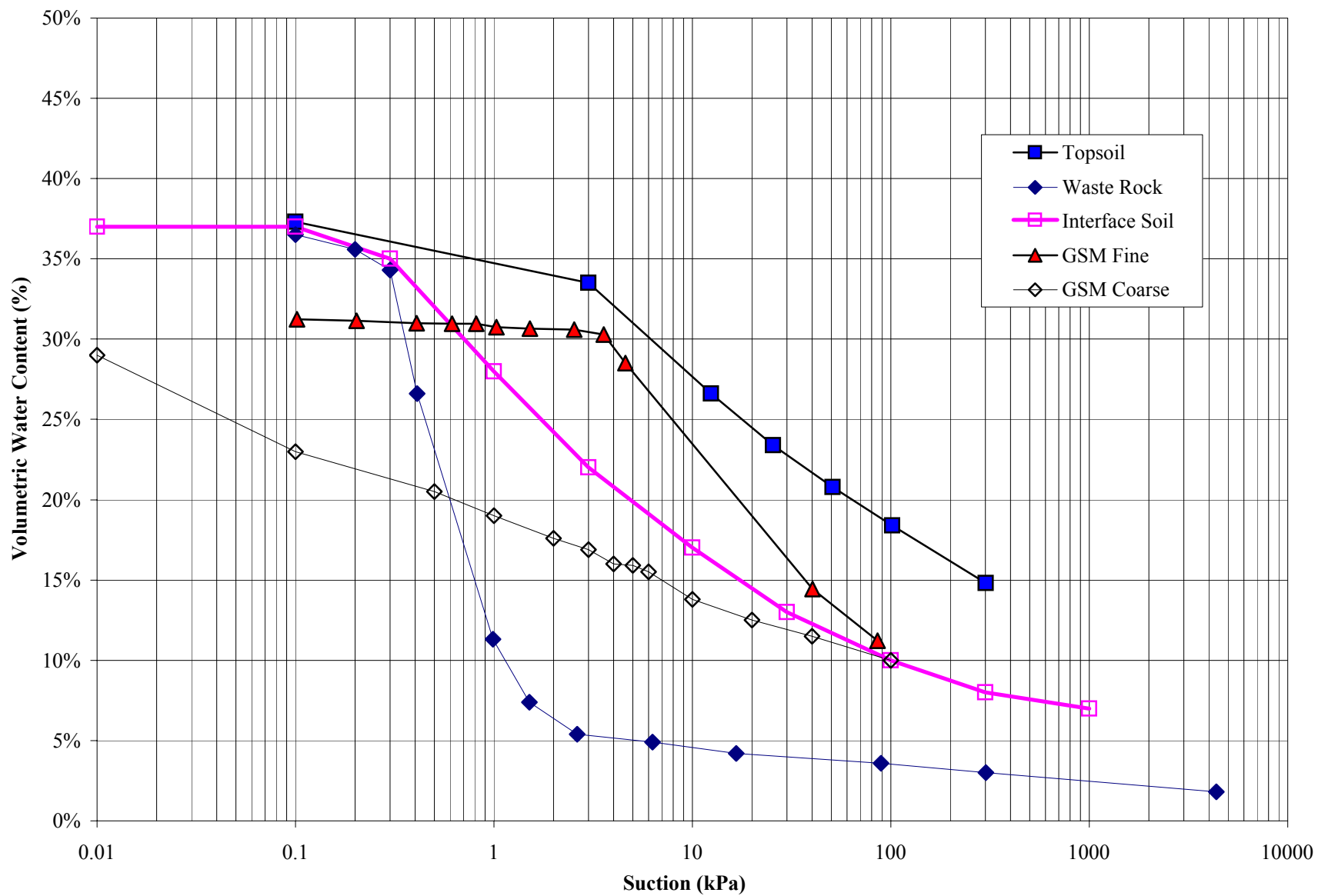
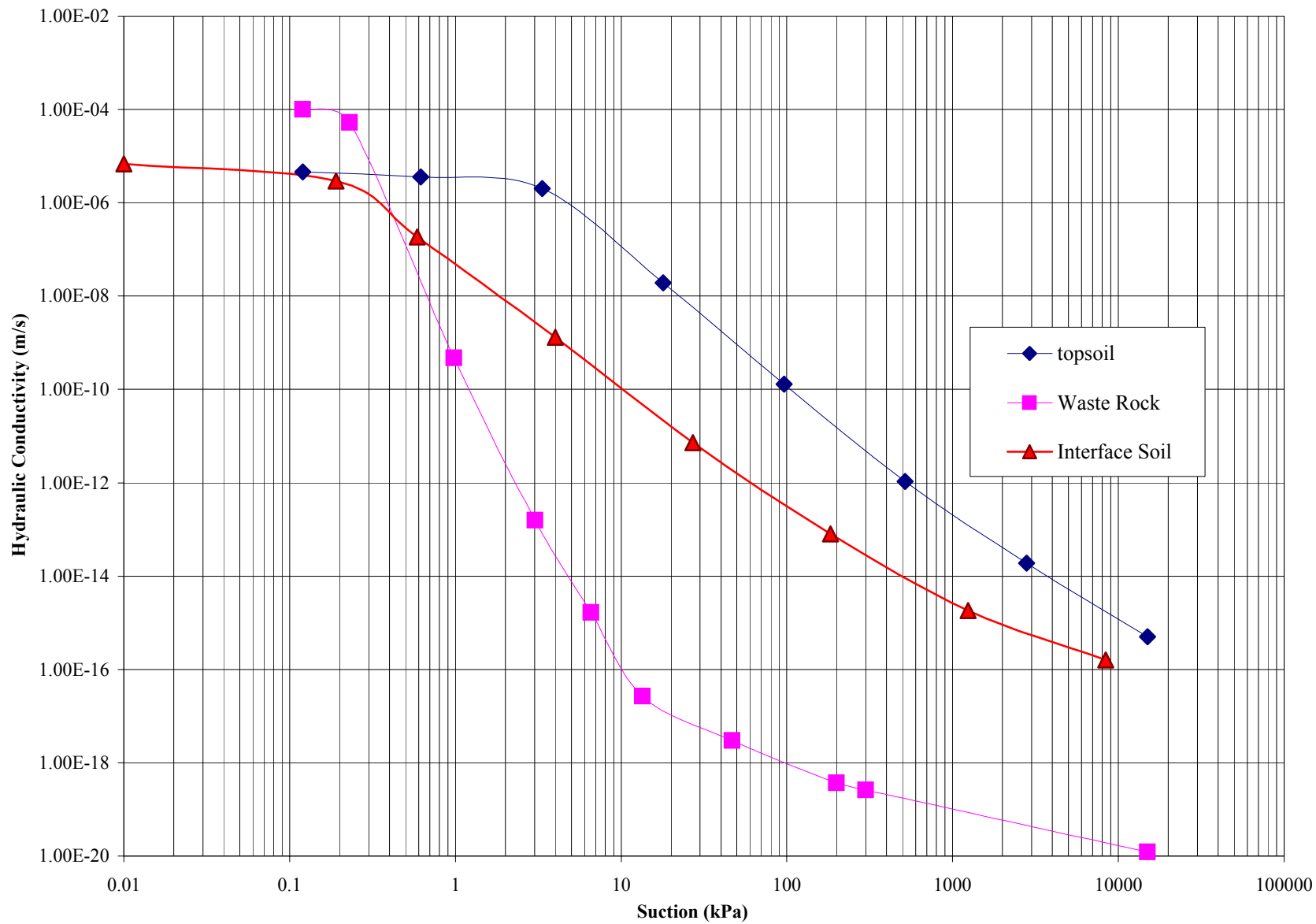


FIGURE B-19 - SOIL WATER CHARACTERISTIC CURVE (SWCC) OF COVER MATERIAL (TOPSOIL) AND MINE ROCK USED IN 2D SEEP/W MODEL.



**FIGURE B-20 - HYDRAULIC CONDUCTIVITY FUNCTION
OF COVER MATERIAL (TOPSOIL) AND MINE ROCK
USED IN 2D SEEP/W MODEL.**

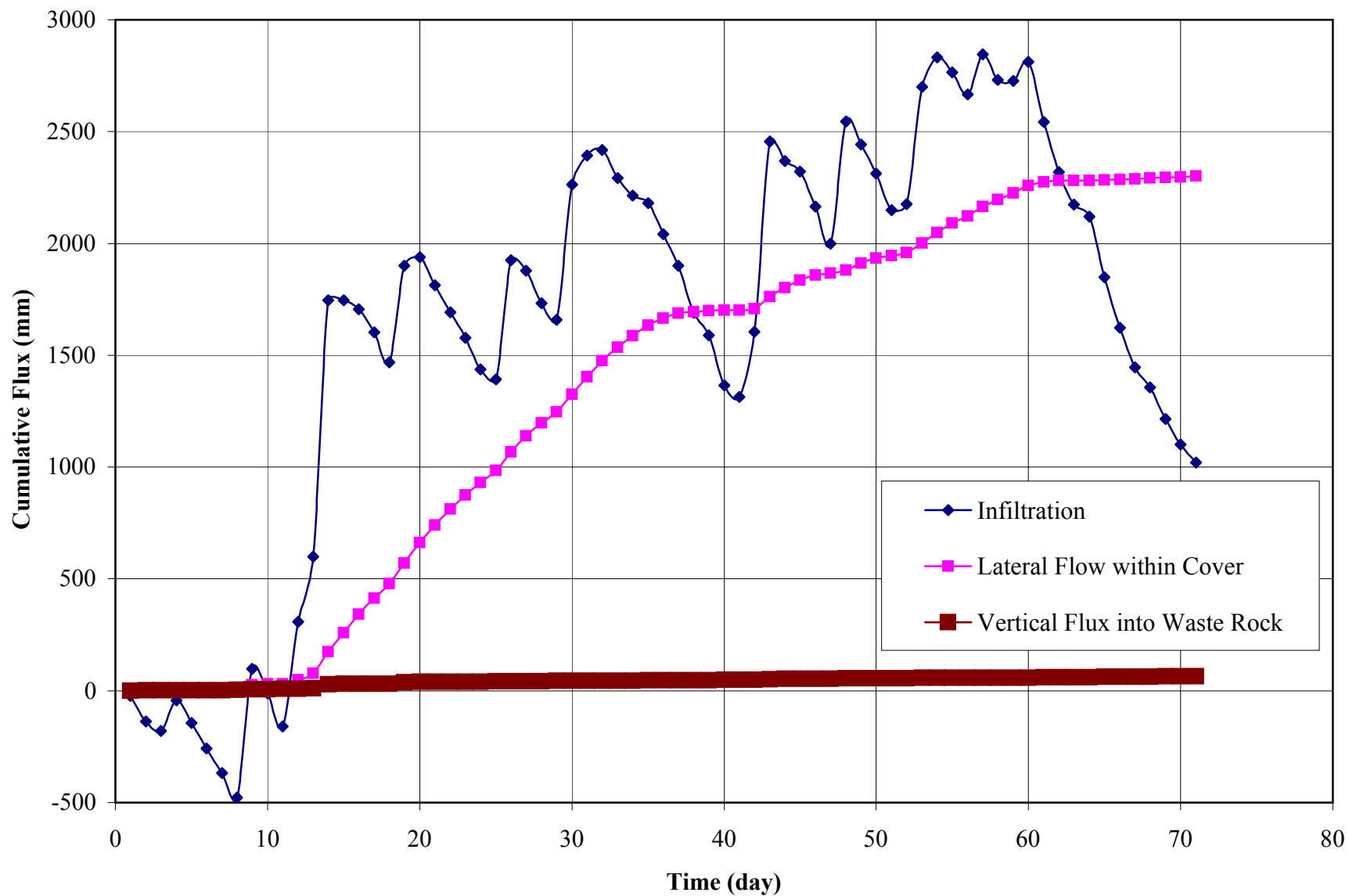


FIGURE B-21 - CUMULATIVE FLUXES FOR SLOPED MINE ROCK (3:1) COVERED WITH 24 INCHES OF TOPSOIL (DEFAULT MINE ROCK PROPERTIES).

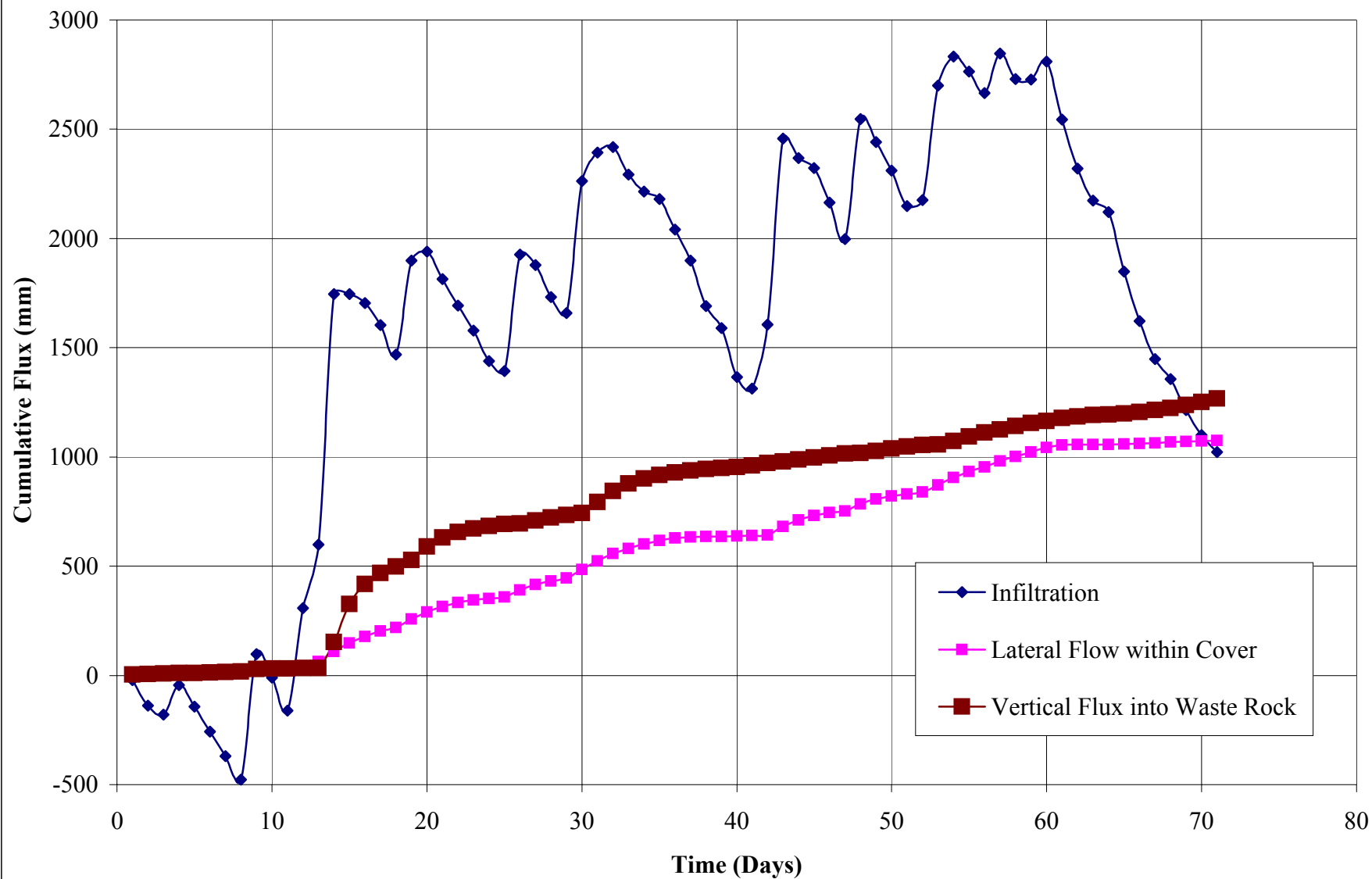


FIGURE B-22 - CUMULATIVE FLUXES FOR SLOPED MINE ROCK (3:1) COVERED WITH 24 INCHES TOPSOIL ('FINER' MINE ROCK).

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